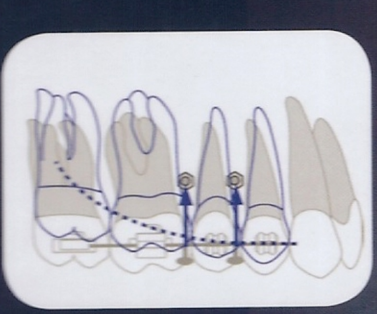
Orthodontics

Current Principles and Techniques



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PREFACE

This is the fifth edition of what remains the most widely used graduate orthodontic textbook in the world. For over 25 years it has contributed to the education of orthodontic residents and practitioners around the world, having been translated into eight different languages. The success of the text is due to the hard work of the core contributors as well as new authors who have updated and added to the material being presented. The orthodontic specialty is indeed a dynamic one with an ebb and flow to discoveries and new knowledge that impacts clinical orthodontic treatment. Each edition of this text has been testimony to advances being made in allied fields that improve our understanding of basic biologic mechanisms, new techniques and technologies, and patient management.

In completing this fifth edition we were challenged to match the changes in the orthodontic specialty with an increase in scope of the text while maintaining the size of the volume in its present form. Thus we were faced with the need to consolidate some of the chapters from the previous editions and cut the length of others as we presented new chapters to provide the most current and relevant information. In some instances, we have opted to place material on a companion website, a practice that has found increasing acceptance throughout the healthcare professions. This additional material expands the breadth of the written text. It is our expectation that we will be able to use the companion website as a means by which we can not only provide adjunctive material but also update our information in the period between the release of this edition and an expected sixth edition in the future. The rapid evolution of the basic and clinical sciences demands that we use the best information-sharing technologies and maintain an up-to-date presentation.

In characterising our efforts as editors, Tom Graber said it best in this preface paragraph from the fourth edition: "The editors have assiduously tried to provide a balance of basic science, diagnostic aids (choice and differential application), critical use, and a broad spectrum of clinical tools, that is, therapeutic mechanisms that achieve the best possible treatment results with optimal tissue response, minimal iatrogenic potential, the most favorable patient compliance, and stable results, in the shortest possible treatment time." We believe these efforts have provided our orthodontic colleagues with the latest and the best!

Chapter 1: *The Decision-Making Process in Orthodontics*. This chapter has been completely revised and updated to include advances in technology and their applications to diagnosis and treatment planning. Additionally, the new methodological approach of systematic reviews of the literature in evaluating the efficiency and effectiveness of different treatment options strengthens our understanding of using the best evidence to provide alternative treatment plans for patients. In an era in which choice of a treatment is a partnership between the clinician and the patient, providing decision analysis and prior probability estimates of outcomes is an obligation for all clinicians. The advent of well-designed clinical trials has provided new and important information to patients, parents, and providers in the increasingly computer literate age of the 21st century.

Chapter 2: *Special Considerations in Diagnosis and Treatment Planning*. With the advances described in the previous chapter it has been necessary to devote a chapter to specific and special considerations in diagnosis and treatment planning, including enhancements in dental and facial aesthetics for consideration in orthodontic clinical practice.

Chapter 3. *Psychological Aspects of Orthodontics*. This chapter discusses the psychological health of the young child that is critical to success with early-treatment patients. This chapter succinctly describes perceptions of the normal adolescent, difficult patients, and individuals with psychological illnesses and medical problems, an understanding of which is important to achieve optimal therapy. This concise new information is not readily available and is key to achieving better patient management.

Chapter 4: *Craniofacial Imaging in Orthodontics*. The focus of this chapter is to provide the historical basis of two-dimensional imaging and recent developments in three-dimensional imaging. This has transformed our appreciation of conventional cephalometric analysis to three-dimensional volumetric imaging and cone beam computed tomography (CBCT). Contemporary and evolving imaging techniques make up a fast-moving field in diagnosis, and this chapter provides updated information relevant and essential to the practicing orthodontist.

Chapter 5: *Genetics and Orthodontics*. Our understanding of genetics, which originally focused on heredity, has moved rapidly in an era of shifting paradigms and beliefs as the human genome sequence was unraveled at the beginning of the 21st century. This chapter has been updated with new material. The roles of the geneticist and dysmorphologist have become integral to craniofacial teams and indispensable in diagnosing children born with cleft lip/palate as syndromic or nonsyndromic. Genetics is also involved in the development of malocclusion and is important in the prediction of growth and development, including dental anomalies and their phenotypic expression. Our understanding of genetic influences has become important in predicting external apical root resorption and individual variation

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in the response to treatment. How environmental factors affect gene expression and malocclusion will determine an individual's response to treatment interventions.

Chapter 6: *The Upper Airway and Craniofacial Morphology* has been revised and is a scientific appraisal of all dimensions and possible relationships among natural head position, mode of respiration and cranial morphology, tomography and surgery of the upper airway, and allergies. Emphasis has been placed on practical aspects such as obstructive sleep apnea and the orthodontist's role.

Chapter 7: *Orthodontic Therapy and the Temporomandibular Disorder Patient*, is by the leading authority on temporomandibular disorder (TMD) in the world, Jeffrey P. Okeson. He has called upon Kazumi Ikeda to present unique new material on condylar adaptation with TMD treatment. In addition, this chapter covers the concept of orthopedic stability, the musculoskeletal stable position, how to evaluate patients for TMD, the development of orthodontic/TMD treatment plans, and the management of TMD symptoms that arise during orthodontic therapy. With the proliferation of malpractice suits in this field, it is incumbent on all of us to study and assimilate the information presented in this chapter.

Chapter 8: Craniofacial Growth and Development: Evidence-Based Perspectives. An understanding of growth and development and adaptive change within the craniofacial complex is critical for the orthodontist in all phases of clinical care. From diagnosis to treatment planning to the execution of a therapeutic intervention, the clinician must consider how developmental changes have influenced and will influence the patient. Chapter 8 is a new contribution to this text, although the concept that orthodontics is biologically based is an old one. The explosion of new information in recent years, much of which is not covered in the traditional orthodontic literature or reviewed in many dental school curricula, necessitated the inclusion of this material in the fifth edition of our text. This chapter reviews the basic anatomical and functional structures within the craniofacial complex and, starting with prenatal development, describes the complex interrelationships influencing form and function. Drs. David Carlson and Peter Buschang, well known and respected individually, have teamed to present this material in a manner most relevant to the orthodontic specialist.

Chapter 9: Tissue Reactions in Orthodontics. From the first edition of this text, a critical component was an understanding of the basic biologic events underlying tooth movement. The first four editions featured as primary contributors the recognized research pioneers on tooth movement of the last century, Drs. Kaare Reitan and Per Rygh. They were joined by Dr. Birgit Thilander in the third and fourth editions, and Dr. Thilander has authored the current chapter. Internationally recognized as the authority on tissue response to tooth-moving forces, Dr. Thilander provides an initial review of the tissues involved followed by an in-depth discussion of physiologic tooth movement, tissue reactions to various forces placed on the periodontium, and posttreatment changes. Of course, as orthodontists we must also understand craniofacial growth sites and the temporomandibular joints and how these may be influenced by our therapies. The reactions to orthopedic forces of sutural tissues and the temporomandibular joints, along with the associated considerations needed for planning dentofacial orthopedic treatment, are presented.

Chapter 10: *Bone Physiology, Metabolism, and Biomechanics in Orthodontic Practice*, is a landmark contribution by another global leader in the field, W. Eugene Roberts. He is both a world-class researcher and a clinician and is admirably qualified to tie biomechanics, bone physiology, and anatomy together in a meaningful manner. His section on osteology discusses the different structures of the maxilla and mandible, temporomandibular articulation, and clinical correction via case studies. The comprehensive analysis of bone physiology presents the specific assessment methodologies and the best information from each. He classifies bone tissue as it affects our ministrative efforts, skeletal adaptation, cortical bone growth, and maturation. Equally important is the information presented on bone metabolism, calcium conservation, skeletal compromise, biomechanics, sutures, and orthodontic tooth movement and potential iatrogenic response. Also included are discussions on periodontal ligament response, osteoblast histogenesis and bone formation, and osteoclast recruitment and bone resorption. The final clinical correlation section ties it all together, with a special section on a topic dear to the heart of Roberts because of his pioneer research and clinical application of endosseous implants of all types. The importance of this portion is evidenced by the drawing of the latest retromolar implant, serving to retract teeth anterior to it. Like so many of the other chapters, this chapter alone makes the book worthwhile for the clinician and would-be orthodontist!

Chapter 11: *Application of Bioengineering to Clinical Orthodontics*. Although orthodontics is biologically based, the physical sciences provide the important basic principles for orthodontic appliance design. This chapter, written by one of the recognized leaders in the area of orthodontic biomechanics, Charles Burstone, brings together physics, mathematics, and engineering to provide the theoretical background for appliance construction and manipulation. Specific topics include discussions of the following: biomechanics of tooth movement (centers of rotation, force magnitude, optimal force, and stress), orthodontic appliance components, mechanical properties of wires, selection of proper wires, influence of wire size-length cross-section, archwire design, and the role of friction.

Chapter 12: *Biomechanical Considerations with Temporary Anchorage Devices*, is a completely new chapter written by world leaders in the clinical efficiency of

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temporary anchorage devices (TADs), Drs. Young-Chel Park, Jung Kook Kim, Young-Chel Park, and Jong Suk Lee. These authors have published many books, papers, and lectures and are the ultimate sources of authority on TADs around the world. They cover characteristics, limitations, and clinical biomechanics of TADs to aid in achieving efficient applications, as well as proper design of mechanics to achieve specific treatment objectives.

Chapter 13: *Interceptive Guidance of Occlusion with Emphasis on Diagnosis.* As orthodontists, our goal is to provide the best in overall treatment with a minimum of mechanotherapy. Drs. Jack and Hali Dale discuss developmental stages and timing and how these considerations must be integrated into a therapeutic model for patient care. Of course, a good diagnosis requires excellent records to initiate the orthodontic evaluation process, document the patient's care, and review results following treatment. These requirements are detailed along with a description of the considerations that should arise from each of the record components. Clinical analysis of the mixed dentition, including space analysis, is the basis for decision making on early removal of primary and/or permanent teeth. Key cephalometric measurements are detailed to describe the important dental, skeletal, and facial esthetic considerations for the clinician. This chapter closely coordinates with Chapter 15 to provide the Tweed-Merrifield perspective on optimal clinical care, dental and facial esthetics, and stability of results throughout life.

Chapter 14: *Optimizing Orthodontic and Dentofacial Orthopedic Treatment Timing.* The issue of "when to treat" is carried a step further in this chapter by Drs. James A. McNamara, Laurie McNamara, and Lee W. Graber. Starting with a discussion on evaluating skeletal maturation, there is an in-depth review of treatment timing and appliances for various malocclusions. With an understanding of craniofacial growth and development, the clinician is armed with basic information that underlies the selection of interventions at appropriate times. The different optimal developmental periods for appliance intervention are detailed in this chapter along with a description of appliance fabrication and technique. There are a myriad of different orthodontic and orthopedic appliances available today, but the authors have focused on some examples that have repeatedly proved successful and are supported by clinical research. The concepts that underlie these therapeutic approaches may be extrapolated to be used with similar appliances.

Chapter 15: *Standard Edgewise: Tweed-Merrifield Philosophy, Diagnosis, Treatment Planning, and Force Systems.* This chapter has been reduced in length while maintaining the essence of orthodontics and complex wire-bending before the evolution of prescription brackets and the straight wire appliance. Tweed philosophy and technique was designed to manage malocclusions when extractions were indicated to relieve crowding as opposed to arch expansion to accommodate all the teeth. Although the Tweed-Merrifield edgewise appliance is the direct descendent of the appliance invented in 1928 by Edward H. Angle, it is taught and used with a different philosophy by a new generation of contemporary orthodontists.

Chapter 16: *Contemporary Treatment Mechanics Using the Straight Wire Appliance,* by two superb clinicians and educators—Drs. Antonino G. Secchi and Jorge Ayala—presents a new overview of the straight wire appliance concept and how it integrates with self-ligation. The authors break down treatment mechanics into three stages, providing detailed tooth movements and goals to be achieved during each stage. In addition, wire sequences, anchorage preparations, and optimal finishing are emphasized to allow the clinician to better understand the system from the beginning to the end of treatment. Well-documented case studies illustrate key features and make the material clear and practical. This chapter is a must-read guide for the practicing orthodontist using fully adjusted appliances.

Chapter 17: *Self-Ligating Brackets: Theory, Practice, and Evidence.* The popularity of self-ligating brackets was based on their design, which made them more efficient and effective than conventional brackets. While this has not been fully supported by clinical trials, new advantages have emerged with new technological developments in the bracket. Secure ligation without elastomeric modules or chains has improved the cleanliness of the appliances with the advantage of full engagement of aligning archwires, resulting in tooth control and longer intervals between appointments without the decay of elastomeric forces and accumulation of biofilm.

Chapter 18: *Lingual Orthodontics with Completely Customized Appliances.* New developments in the lingual appliance have resulted in customized brackets and archwires, which are described and illustrated in this chapter. While lingual appliances have been considered invisible and therefore the most aesthetic of orthodontic appliances, they present certain technological challenges for the orthodontist both in visualizing and in applying biomechanical forces traditionally designed for the labial or buccal aspect of the tooth. The elimination of decalcification is a major advantage of the lingual appliance, and customized brackets have increased the comfort level and tolerance of the appliance.

Chapter 19: *Clear Aligner Treatment.* Thermoform clear aligners have been used in orthodontics as an aesthetic alternative to the Hawley retainer with a labial bow. These typically are fabricated in the orthodontist's office to maintain the position of teeth in retention. Active aligners have been marketed by the proprietary orthodontic technique of Invisalign, in which a series of computer-generated aligners actively and aesthetically guide teeth into alignment without fixed appliances. This new chapter provides a contemporary overview of clear aligners illustrated with case studies and discusses the selection of appropriate cases.

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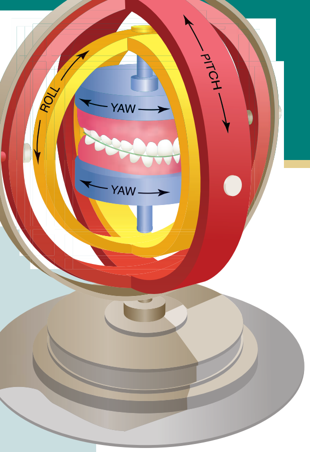

CHAPTER

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The Decision-Making Process in Orthodontics

James L. Ackerman, Tung Nguyen, William R. Proffit

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In the 40 years since the first edition of this textbook, the world has changed dramatically and there have been significant scientific and technologic transformations in dentistry and the specialty of orthodontics. In the intervening years there has been a considerable change in the definition of *overall health,* an increased patient role in making his or her own health care decisions, and social and political forces that have affected the funding of health care. Nevertheless, the fundamentals of orthodontics have remained largely the same despite these dramatic changes.

Our greater awareness today of how humans have evolved as social primates has clarified the role of anterior tooth display ("straight teeth and a nice smile") in signaling fitness in a modern society. In the last quarter century, a shift in societal values and pressures has greatly influenced the decision-making process in orthodontics, placing greater emphasis on patient autonomy. Forty years ago, almost all orthodontists viewed their role as correcting malocclusions by straightening teeth. Today, most orthodontists see their mission in the broader context of improving facial and dental appearances as well as the relationships of the teeth to each other.

Unfortunately, despite this trend, one of the finest treatment modalities available to orthodontists for addressing the most severe dentofacial conditions is dramatically on the wane. Orthognathic surgery, for patients whose dental and jaw disparities are beyond the range of conventional orthodontics, is being performed less often because of greater rationing of health care dollars by the insurance industry. This is an example of how economic factors can and do shape orthodontic practice.

In an operational sense, the goals of orthodontic treatment are to:

- Improve smile and facial appearance with resultant improvement in an individual's social well-being and quality of life.
- Obtain optimal proximal and occlusal contact of teeth (occlusion).
- Establish normal oral function and performance, allowing for an adequate range of physiologic adaptation.
- Achieve stability of the dentition within the bounds of expected physiologic rebound.

This chapter is written primarily for residents in orthodontics and current practitioners who want an update on the changes taking place in orthodontics. The major focus is on the changes in evaluation and treatment planning that have affected orthodontics in recent years. Because the purpose is to outline the basics of orthodontic assessment and treatment planning without going into detail about all aspects of the process, it should be used as a companion piece to the first three sections of *Contemporary Orthodontics.*[1] It is also a natural segue to Chapter 2 in this text, which is a detailed analysis of dentofacial appearance from an orthodontic point of view.

In keeping with the title of this book, this chapter emphasizes the principles of orthodontics rather than the equally important techniques of orthodontics, which many of the other chapters in this compendium address. That said, it should be pointed out that there is no orthodontic technique that in the absence of a cogent diagnosis and treatment plan can consistently produce effective outcomes. A competent orthodontist today must use broad background information in the life sciences and social sciences in assessing an orthodontic condition and planning treatment based on a comprehensive evaluation. The many steps in the decision-making process in orthodontics that are quickly and seamlessly telescoped in routine practice are delineated here as a practical guide for everyday practice.

BACKGROUND CONCEPTS

Quality of Life: The Modern Health Care Paradigm

Until fairly recently, the most widely held view of "health" was merely the absence of disease or infirmity. Orthodontists struggled for many years to find a scientifically acceptable definition of "orthodontics and malocclusion" within the confines of this narrow definition of health. Today, the World Health Organization (WHO)'s broader concept of health as a state of complete physical, mental, and social well-being is universally embraced.[2] This definition first appeared in the Preamble to the Constitution of the WHO as adopted by the International Health Conference in 1946. From this expanded view of health has emerged an era in medicine and dentistry in which enhancement in quality of life takes precedence over almost any other aspect of health.

For orthodontics and many other dental and medical specialties, this has tipped the scales from greatest emphasis on function and performance to far more weight placed on appearance. The idea that appearance is often valued more than performance is simply a fact of life. According to evolutionary psychologist Geoffrey Miller, "Our vast social-primate brains evolved to pursue one central social goal: to look good in the eyes of others."[3] In some respects, the role of facial appearance and smile esthetics and their psychosocial ramifications for promoting social well-being and improvement in a patient's quality of life have been the "elephant in the room" in orthodontics—that is, everybody knew they were there but were unwilling to acknowledge their presence despite their considerable dimensions. Nearly every specialty of medicine and dentistry now offers interventions that are not treatments per se but instead enhancements of normal traits or conditions. Medical examples are onabotulinumtoxinA (Botox) for wrinkles, growth hormone therapy to increase a child's stature, and medications like fluoxetine (Prozac) for patients who desire to feel "better than well."[4] In dentistry, tooth whitening, clinical crown lengthening, and porcelain veneers are examples of enhancement technologies designed to transform normal conditions to states beyond normal. This trend has had remarkable implications for orthodontic treatment planning.

Other Influences on Recent Change in Orthodontics

Enhancement as an Appropriate Treatment Goal. In the early twentieth century, as Angle shaped orthodontics as a specialty, his assertion that malocclusion posed a threat to long-term oral health by limiting effective oral hygiene and by causing imbalance in occlusal loading seemed reasonable. Yet over the past 100 years, no compelling evidence could be brought to bear to support this notion.[5,6] Casting doubt on the oral health basis for orthodontic intervention has had the positive effect of redefining orthodontics' reason for existence in a modern world and has created a better understanding of the social and societal trends that influence why patients seek orthodontic correction. We now realize that from a patient's or parent's perspective, the appearance and psychosocial benefit of orthodontic enhancement often have higher value than the occlusal outcome of treatment. Although the measurable improvement in patient self-image and self-esteem subsequent to orthodontic enhancement is not dramatic, the patient's perception of improved social well-being and quality of life has been demonstrated.[7–10] Stated bluntly, an orthodontist who views his or her role in society simply as one who corrects dental occlusion is clearly missing the larger picture. For further consideration of the topic of the psychological aspects of orthodontic diagnosis and treatment, the reader is referred to Chapter 3.

By the end of the twentieth century, society had set aside its taboo against medical or dental interventions aimed principally at improving appearance, dispelling the view that unless treatment was necessary to control disease or functional problems, it was somehow frivolous. Acceptance of the idea that enhancing appearance is not motivated merely by vanity but rather is a means of improving social well-being and quality of life was a major philosophical shift in the outlook of the specialty of orthodontics. People seek whatever help they can obtain to enhance their ability to signal others as a means of communicating, realizing that more attractive faces and smiles favor more effective signaling.[11,12] By the same token, orthodontists do not establish in isolation the value of their service, because the benefit of orthodontics is a subjective judgment made by the parent and/or patient. In this context, setting goals for orthodontic treatment becomes a shared activity between orthodontist and patient.

Informed Consent, Practice Management, and Commercialization

A major change in orthodontics has resulted from the reinterpretation of the legal doctrine of informed consent, emphasizing the ethical imperative of greater respect for patient autonomy in the decision-making process.[13] In the contemporary paradigm, the orthodontist no longer makes decisions alone but now does so jointly with the patient and/or parent. Arguably this change in approach has had greater impact on orthodontic treatment planning than any technical innovations, even those as dramatic as distraction osteogenesis, temporary anchorage devices (TADs), self-ligating brackets, clear aligner therapy, three-dimensional imaging, or other computer applications. See Chapters 12, 17, 19, and 20 for further discussion of these topics.

In the past, there was a significant disconnect between what was taught in orthodontic residency programs and how things were done in practice. Although the subject of practice management was popular at orthodontic meetings, the term itself had a somewhat pejorative connotation, particularly in academic circles. Today, it is well accepted that orthodontics is an enterprise like any other practice in the health care industry, and it is also understood that health economics will continue to drive the medical and dental marketplace in the future. For that reason, many orthodontists in practice have switched from a three-step treatment-planning process to a one-step procedure for many, if not most, of the patients in a typical orthodontic practice. Instead of prospective orthodontic patients simply having an initial evaluation on their first appointment, a second appointment for records, and then a third appointment for a patient/parent conference, all three tasks can now usually be accomplished during the first visit.[14]

Many orthodontists have the distinct impression that an increasing proportion of their practice today consists of children who are less compliant with treatment than patients in the past. This has led many practitioners to use "noncompliance" appliances whenever feasible. The two major types of noncompliance treatment are the Herbst appliance, which is nearly 100 years old, and skeletal bone anchors, a recent advance. Although both methods have considerable merit, their availability tends to drive treatment-planning decisions. The old expression, "If one's only tool is a hammer, everything begins to look like a nail" is very apt in describing the impact of noncompliance treatment on the decision-making process in orthodontics. In a more perfect orthodontic world where patient compliance was not such an important factor, a broader choice of appliances would be considered—and for compliant patients, better results might be obtained.

In the past, the great variation in treatment response among patients was too often ignored, and as a result rigid treatment plans were often set and almost religiously adhered to during the course of treatment. It is now well understood that each time a patient presents during treatment, the treatment plan has to be reconsidered in light of the treatment response and/or some element of the original problem that might have been overlooked.

Last, the commercialization of orthodontics has begun to short-circuit certain aspects of diagnosis and treatment planning. It can be argued that the commercialization of orthodontics began with Angle's patenting of his various appliance systems in the early 1900s. Yet it has only been in recent years that direct marketing to consumers by the pharmaceutical industry has influenced commercial companies in dentistry and orthodontics to do the same. The classic example has been Invisalign's advertising campaign to influence prospective orthodontic patients. Unfortunately, other orthodontic suppliers are beginning to follow this malign example. The impact has been felt greatly in some of the decision-making aspects of orthodontics. It is a common occurrence in practice now for a patient to present simply with the question of whether they are a good candidate for Invisalign treatment. The orthodontist's role in this circumstance is not to establish a problem list and determine the various treatment options but rather to cut to the chase and make the not very difficult determination as to whether a series of thermoformed trays could be effective for that individual's particular orthodontic condition.

Technological Advances

New methods that have affected current orthodontic practice and have even greater potential for changing the way orthodontists will practice in the future include digital photography, videography, 3D photography, computer imaging, virtual dental models, cone beam computed tomography, stereolithographic models, and custom milling of attachments and robotic wire bending. Nonetheless, technological innovations should not be confused with fundamental changes in orthodontic thinking. It is similar to when recorded music became digital. The tone of the music improved, but the tune remained the same. This can be the litmus test for a clinician considering the adoption of any new technology. Will it change the tune or simply the tone? The new technologies in orthodontics are summarized next.

Digital Photography, Videography, and Three-dimensional Photography. The conversion of photography from an analog to a digital process has revolutionized imaging in all fields, with orthodontics very much the beneficiary of this stunning technological advance. The ability of digital video to capture the dynamics of anterior tooth display during speech and smiling has not yet been fully embraced despite the information that can be gleaned from this type of record.[15,16] The latest development of three-dimensional facial photography[17] has great potential in orthodontics, and when it has been perfected and its current high cost has been overcome, it will undoubtedly be a useful research and clinical tool. Prior to the era of facial photography, orthodontists used plaster facial moulages to document facial appearance and changes in soft tissue facial contours that occurred as a result of growth, maturation, and treatment. These records were excellent facsimiles since they were three-dimensional reproductions. President Lincoln had two life masks made in 1860 and 1865. Although there were only 5 intervening years between them, the marked change in Lincoln's facial appearance has been attributed to the stress of the Civil War. The laser scans also show Lincoln's face to be slightly asymmetric, which had been suspected for some time. Thus, the quest for effective three-dimensional imaging of the face for orthodontic purpose is not new. The obvious drawbacks of facial moulages were the inordinate labor involved in producing them and the remarkable difficulty in storing them. The commercialization of photography allowed orthodontists to quickly abandon the use of facial moulages over a century ago. Angle's seventh edition was the first textbook in orthodontics to use facial photography. Obviously, the drawback of facial photography was and still is that it is not three-dimensional. The excitement over three-dimensional photography in orthodontics is that it combines the advantages of facial moulages and facial photography, including the fact that the images are in color (Figure 1-1, *A–C*).

Computer Imaging. The ability to morph images with special computer software and the creation of algorithms that can simulate the facial outcomes of tooth and jaw movement provide an excellent treatment planning and communication tool in orthodontics[18,19] (see Case Study 1-2, page 52).

Virtual Dental Models. Models of the teeth, the traditional diagnostic record from the beginning of orthodontics, have been used to view the relationships of the teeth from any orientation. The advent of digitized laser-scanned dental impressions that produce a three-dimensional image of the teeth has overcome the problem of having to pour and trim plaster casts and has obviated the need to store and retrieve the models each time a patient is seen. Now it is possible to view a virtual dentition on a computer screen by rotating the virtual models to allow the same type of three-dimensional view as hand-held models. In practices where 75 to 100 or more patients are seen each day, the task of "pulling models" becomes an onerous task for the orthodontic staff. Thus, the push by orthodontists toward the paperless office has represented a real advance in practice efficiency. As well, in a multioffice practice where patients are occasionally seen at more than one location, the innovation of using all digital records has been a real boon. These visual representations can be measured with at least as great accuracy as plaster models that are measured with calipers, and it is likely that this technology has not yet matured to its full potential[20,21] (Figure 1-2).

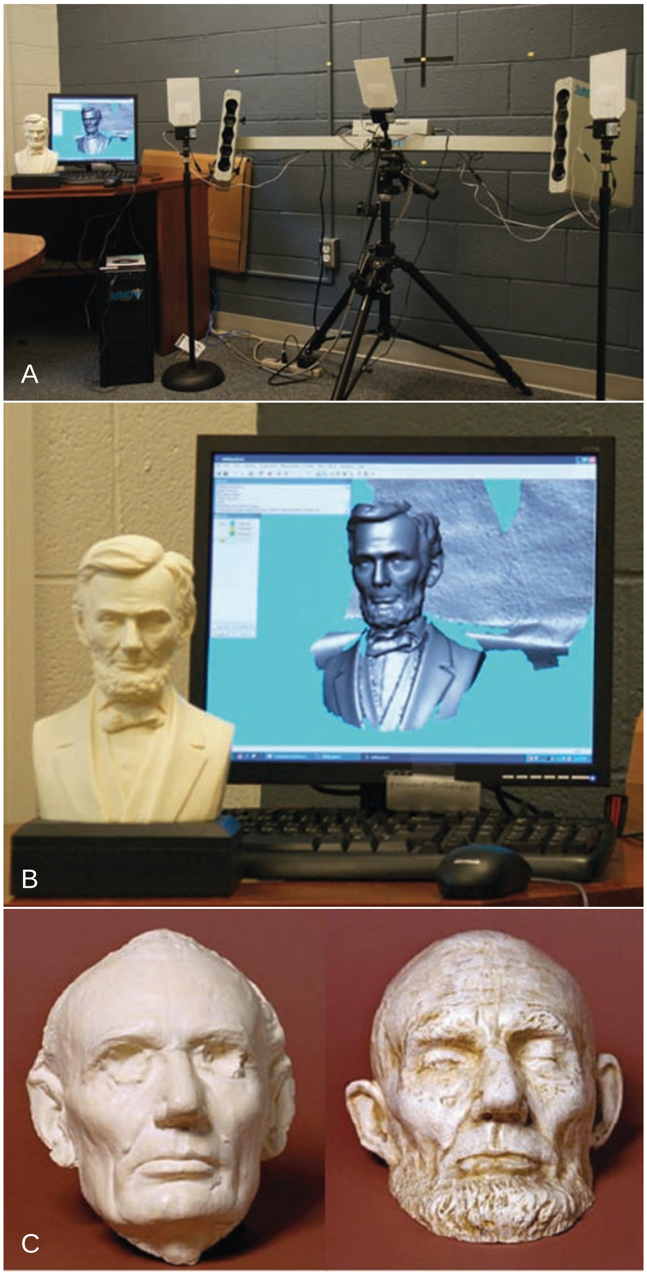


FIGURE 1-1 **A,** Three-dimensional imaging device consisting of multiple cameras mounted at different angles with the separate images integrated in similar fashion to computed tomography. **B,** Bust of Lincoln with three-dimensional image capture (rendering) on the computer screen. **C,** Laser scans of two life masks (facial moulages) of Lincoln done in 1860 and 1865. Three-dimensional photography, in its present form, has nearly reached the level of quality that can be achieved with a facial moulage, plus the images are in color. Thus, this new technology is exciting and shows great promise. Nevertheless, one has to ask, "Does this advance represent a change in the tune or merely its tone"?

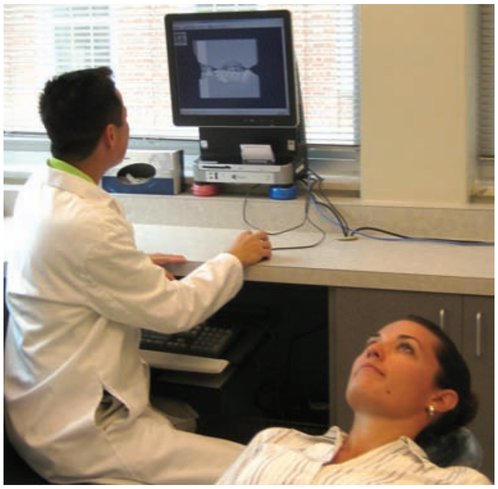


FIGURE 1-2 For complex orthodontic problems, it is sometimes useful in diagnosis and treatment planning, as well as for monitoring treatment progress, to look at three-dimensional (virtual) study models at chairside rather than two-dimensional intraoral photographs. As shown in this image, if one wants to observe the supporting cusp–fossae occlusal relationships, it can only be done with study models (virtual or otherwise). One cannot see this aspect of occlusion either clinically or with intraoral photographs.

In a somewhat humorous vein, it is interesting how deeply ingrained orthodontic traditions and rituals are, such as insisting on having simulated plaster bases on virtual orthodontic models. In days gone by, the trimming of orthodontic models actually served a purpose, by making it more obvious if the dental arches were asymmetrical. Today, these bases are primarily decorative yet they remain. By far the greatest limitation of plaster casts and virtual models is that although they are excellent facsimiles of the crowns of teeth, they give no clue about three important traits:

1. The inclinations of tooth roots in relationship to their alveolar housing. After all, the critical elements in the biology of tooth movement are the tooth roots in relationship to their surrounding bone.
2. The relationship of tooth crowns to the soft tissues of the tongue and lips. In the long run, it is this relationship that determines functional stability of the dentition.
3. The relative inclinations of tooth crowns in relation to the overall skeletal and soft tissue facial framework. In the end, dentofacial appearance is a critical factor in assessing orthodontic outcome.

Cone Beam Computed Tomography. Cone beam computed tomography (CBCT) produces three-dimensional volumetric images that can be reliably measured.[22] A major advantage of CBCT imaging is that all extraneous structures that would otherwise obscure the desired view can be excluded. This allows visualization of dimensions and attributes that were indeterminate

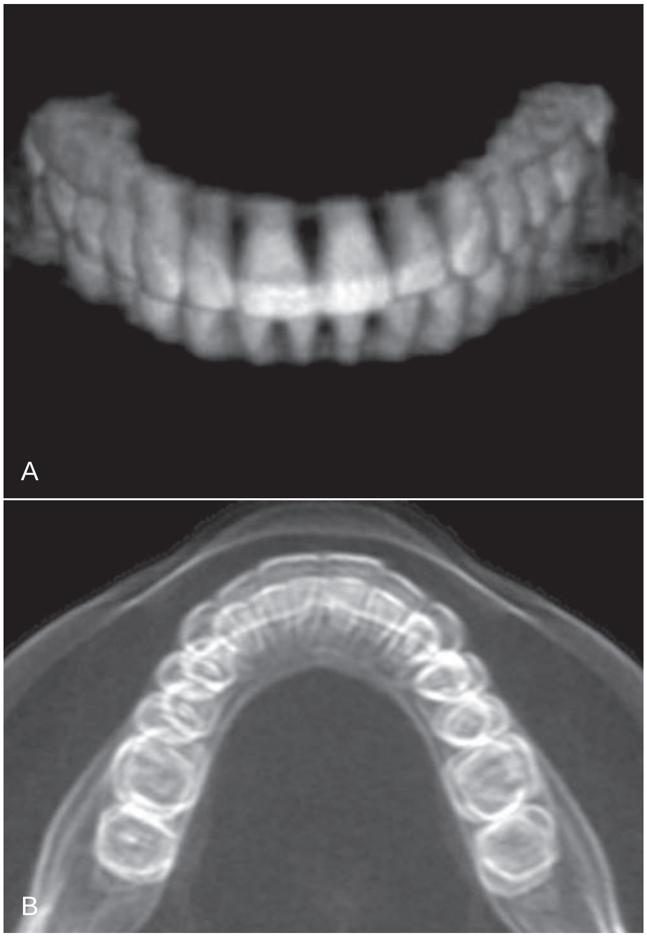


FIGURE 1-3 This illustration shows that if for any reason one wanted to radiographically examine the crowns of teeth and their alveolar support only, without seeing the superimposition of other maxillary or mandibular structures, it can easily be accomplished with computed tomography.

previously. Figure 1-3, *A* and *B*, shows two perspectives of an approximately 16-mm block radiographic cross-section of the maxillary and mandibular tooth crowns (8 mm above and below the occlusal plane). The block section can be examined interactively by rotating it on the computer screen in any manner around the *x*, *y*, and *z* axes. This same approach can be applied to virtual models. These digital three-dimensional computer-generated reconstructions create virtual anatomic reproductions that can be visualized from any vantage. This technology has opened new avenues of orthodontic research.

Stereolithographic Models. One of the remarkable benefits of three-dimensional imaging in orthodontics was not appreciated until fairly recently. The concept of producing a stereolithographic model on which an orthodontic appliance could be constructed came as a surprise when announced by Align Technology less than a decade ago, although this approach had been used in craniofacial surgery for some years previously. Stereolithographic models can also be useful as guides in modifying bone plates for rigid fixation in orthognathic surgery, placing dental implants, or placing TADs.[23]

Custom Milling of Attachments and Robotic Wire Bending. Application of computer-assisted design and manufacturing (CAD-CAM) to clinical practice in orthodontics has made great strides recently, with two general approaches. The first application is the creation of customized brackets for individual patients, which will allow the use of "straight wires" to attain closer and closer approximations to theoretically ideal occlusion, versus the alternative approach of using laser scans of the positions of the attachments on the teeth and then having the archwires bent by a robot. Of course, it is possible to use these approaches in combination.[24] Both techniques have considerable appeal, and it will be interesting to see which of these methods prevails in the future (see Chapters 16 and 18).

The reader is referred to Chapters 4 and 20 to learn more about the current state of the art and promise of three-dimensional technology.

Purpose of Orthodontic Treatment

In the nineteenth century, malocclusion was thought to represent an abnormal state, but by the mid-twentieth century orthodontists questioned whether malocclusion was really a malady or a malformation.[25] In the twenty-first century, we recognize that malocclusion is rarely a malady, can occasionally be a malformation, but most often simply represents anatomical variation.[26] Except in genetic disorders of the face and jaws such as craniofacial dysostosis and cleft lip and/or palate, malocclusion should not be thought of as a pathologic condition. As such, orthodontics in many instances is directed toward an improvement in dentofacial appearance and functional stability to a state beyond "normal" and closer to the theoretical ideal. In other words, orthodontics should most often be considered enhancement rather than treatment per se.[27]

When orthodontics is defined in this fashion, it fits nicely into the current model of health, where the goal is improvement of an individual's social well-being and quality of life (QOL). This more recent point of view has made the orthodontist's task easier in regard to determining who might benefit from treatment. Any individual who desires the type of enhancement that orthodontics can provide is most likely a suitable candidate for "braces."

In this era of enhancement, Class I patients with extremely mild spacing or crowding, who not so long ago would have been told their occlusion was within normal limits and treatment was not recommended, can now choose to go beyond normal in pursuit of perfection. The idea of striving to be "better than well," particularly in regard to appearance, is not only accepted but is actually expected. The greater precision of modern orthodontic appliances now allows orthodontists to proceed with confidence when asked to enhance a dentition that is largely within the normal range of variation. One reason that orthodontists are more willing to perform this type of treatment now is that the outcome is far more predictable than it was with earlier appliance systems. For a more in-depth discussion of enhancement, see the excellent monograph "Enhancement Orthodontics."[28]

Evidence-Based Treatment in Perspective

At this point, most orthodontists view evidence-based treatment as a worthy goal but are aware that clinical judgment still is required in planning treatment that will provide optimal benefit to the patient. There are two major reasons for this view:

1. Orthodontists must rely on qualitative societal and cultural standards and conventions in setting treatment goals regarding dentofacial appearance, while recognizing that these standards change over time and information about them is observational rather than experimental. Beauty eludes quantification.
2. It is clear now that variations from ideal occlusion can be acceptable, but there are no good data to delineate exactly what difference it makes to accept various deviations from the ideal. Some of the questions regarding the oral health and psychosocial benefits of orthodontics can be asked in scientific fashion but, because of ethical and practical concerns, are not amenable to being answered with the highest degree of clinical scientific confidence (i.e., with evidence derived from prospective clinical trials).

For these reasons, the decision-making process in orthodontics usually is best considered as bolstered by evidence rather than totally based on it, given the inadequacy of the available data.[29,30] Scientific dilemmas of this type, which transcend the effective range of the traditional scientific method, can be called "trans-scientific" and are not unique to orthodontics.[31] In the absence of sufficient evidence, scientists sometimes have to resort to consensus and collective wisdom in establishing various standards and conventions. So it is with orthodontics.

In previous publications, we proposed the concept of planning orthodontic treatment from a prioritized problem list, which is now a universally accepted idea. It used to be that any morphologic deviation from ideal occlusion was considered a problem. It is now understood that a dentofacial characteristic, like a rotated tooth or a Class II molar relationship, is only a problem if it creates a functional or psychological difficulty for the patient.[32] For pathologic processes, signs and symptoms are differentiated. The equivalent for orthodontics is noting dentofacial characteristics while considering them as problems only if they really create one.

It can be disturbing for orthodontic residents to learn that there is almost always more than one suitable orthodontic treatment plan for any given patient. This is the inevitable result of the tension between the esthetic and occlusal goals of orthodontic treatment—maximizing occlusion may detract from dentofacial appearance, while maximizing appearance may require a compromise in occlusion. It is somewhat analogous to the situation with economic issues: different economists are likely to offer varied solutions, based on their view of what is more important in improving the overall situation. From this perspective, there is likely to be more than one "correct" solution to a patient's orthodontic problems, and the choice will depend on what the orthodontist and patient jointly determine as the primary goal of treatment. Thus, Angle's characterization of orthodontics as an "art and science" still resonates with clinicians today.

Despite this, as we noted initially, better evidence as to the outcomes of varied treatment approaches (including psychosocial as well as occlusal aspects) has great potential to improve orthodontic treatment. Evidence-based orthodontics is discussed in greater detail in Chapter 29.

Understanding "Normal Occlusion"

Normal versus Ideal Occlusion. Prior to the age of enhancement, it was difficult to rationalize the seeming paradox that the majority of the population (about two-thirds according to U.S. Public Health Service survey data) has some degree of irregularity of the dentition or other condition that leads dentists to classify them as needing orthodontic treatment.[33] Usually a typical trait in a population is considered normal and an atypical trait (in this case an ideal arrangement of the teeth) is considered abnormal. In the older model of health care where practitioners treated abnormal conditions or corrected deformities, how could orthodontists justify treating conditions that were neither abnormal nor abnormalities per se?

Obviously, all occlusal traits form a continuum ranging from ideal at one end of the spectrum to significant deviations from ideal at the other. The original proposal of Guilford[34] that any deviation from ideal occlusion should be called "mal-occlusion" created a paradigm in which occlusal traits or characteristics were viewed as a dichotomy (i.e., normal occlusion versus malocclusion). Our current, more nuanced, understanding of the nature and implication of deviations from Angle's theoretically ideal arrangement of teeth has made clear that "malocclusion" is not the best term with which to describe the primary focus of orthodontics. Because of this, we have adopted an alternative term, "orthodontic condition," which was coined some years ago by a committee of the National Academy of Sciences.[32] This encompasses indications for treatment that do not fit the description of "malocclusion." For example, ideal occlusion accompanied by dentoalveolar protrusion with excessive facial convexity and lip incompetence, in a patient whose chief concern is social problems related to appearance, is a definite indication for treatment (one that Angle refused to accept—if you did not like the way you looked with protrusive teeth in ideal occlusion, he questioned your perception). This is more aptly called an "orthodontic condition" rather than a "malocclusion."

Nonetheless, we are not suggesting totally abandoning the term "malocclusion" but rather restricting its use to contexts where its meaning cannot be misconstrued. When describing an orthodontic condition more specifically, one can refer to "dentofacial traits." For example, a midline diastema is a dentofacial trait. In this chapter, whenever possible, we have replaced the term "malocclusion" with "orthodontic condition" and describe the specific characteristics of the condition as "dentofacial traits." The term "dentofacial traits" is used to reflect a broader view of orthodontic conditions rather than just thinking of malocclusions. Orthodontists traditionally thought of hard-tissue structural discrepancies as the major limitation of treatment. Now, however, the soft tissues are acknowledged as establishing the boundaries of dental compensation for underlying jaw discrepancies and thus more effectively determining therapeutic modifiability, or the extent to which an orthodontic condition can be corrected. In addition, there is greater awareness of the importance of anterior tooth display in orthodontic diagnosis and treatment.

Because almost no one has absolutely perfect occlusion, dentists obviously accept some deviation from the theoretical ideal in their definition of normal. If it is not ideal, what are the characteristics that put one individual in the malocclusion category and another in the normal category? To answer this question, we need to examine the concept of ideal occlusion, review existing data for the prevalence of occlusal traits that deviate from the ideal (irregularity, overjet, overbite, etc.), and then review how this relates to oral health, function, and treatment need.

The Concept of Ideal Occlusion. How does the concept of ideal dental occlusion factor into the orthodontist's decision-making and treatment process today? Orthodontists accept the long-standing convention in dentistry of using ideal occlusion as the principal objective and gold standard of orthodontic treatment, while realizing that relatively little data support this core assumption.[13] Even though it is a scientifically flawed standard, because the ideal rarely occurs in nature, the concept of ideal occlusion remains an important and useful arbitrary convention in orthodontics.[35] It is more accurately referred to as the "theoretical ideal." The theoretical ideal arrangement of teeth is still a useful construct in orthodontics both descriptively and as a treatment goal. Although there is great utility in the theoretical ideal for describing dentofacial traits in certain aspects of treatment, it is more realistic to consider a normal range of occlusal variation rather than a theoretical ideal. Of course, the question then becomes, "How do orthodontists define the theoretical ideal and how do they determine the normal range of occlusal variation?" By default, clinical orthodontics has accepted a therapeutic goal, which is best described as the "achievable optimum."[36] In this approach the orthodontist attempts to achieve the best possible occlusion for the patient that is compatible with the other goals of treatment, knowing that only after treatment and retention are completed can he or she truly ascertain the norm for that individual. For further consideration of the retention-relapse issue in orthodontics, see Chapter 27.

In short, the concept of ideal occlusion, which is the very basis of the specialty of orthodontics, has not changed markedly since the original definitions by Bonwill[37] and his student Angle.[38]

Dental and Skeletal Counterpart Compensations: Nature's Way of Camouflaging Discrepancies

Perhaps the most common misperception of beginning residents in orthodontics is the assumption that if theoretically ideal occlusion can be defined, de facto there must be a theoretically ideal arrangement of the supporting structures of the teeth and jaws (i.e., an ideal "skeletal pattern") as well. Nothing could be further from reality. When ideal occlusion exists, it is because there have been three-dimensional compensatory linear and rotational adaptations in the underlying skeleton. These structural alterations can be as far removed from the dentition as the cranial base, the nasomaxillary complex, and the condylar neck and ramus of the mandible. In addition, the corpus of the mandible and the maxillary and mandibular dentoalveolar structures are morphologic features that are remarkably adaptable. Thus, dental compensations can effectively mask underlying anteroposterior skeletal discrepancies. It is no wonder that early orthodontists saw this phenomenon as one more reason to believe that ideal occlusion is nature's intended plan. The simplest demonstration of this is that in Class III skeletal patterns, where either the mandible is too far forward or the maxilla is too far back, the dentition almost always compensates to some extent for the underlying jaw discrepancy. It is as if the teeth are reaching to contact teeth in the opposing dental arch. In other words, the maxillary teeth in this situation often procline and the mandibular teeth retroincline to compensate for the underlying structural discrepancy. The extent to which the teeth are able to compensate determines whether the teeth will be in normal occlusion or an orthodontic condition will exist. The reverse situation occurs when the mandible is too far back or the maxillae are too far forward. In this situation, the teeth usually compensate by the mandibular teeth becoming somewhat proclined and the maxillary teeth becoming

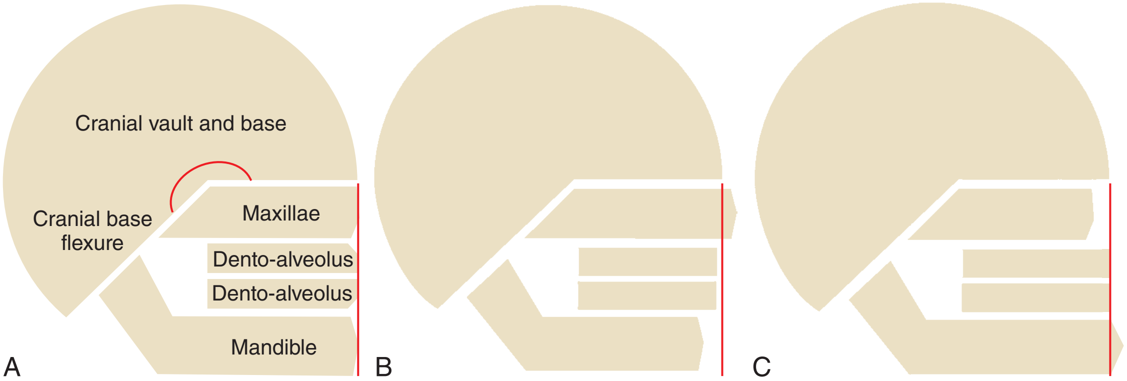


FIGURE 1-4 **A,** Schematic representation of normal jaw proportions and ideal dental relationships. **B,** Schematic depiction of a jaw disproportion characterized by maxillary excess and mandibular retrusion yet ideal dental relationships. In this illustration, normal occlusion is the result of maxillary and mandibular dentoalveolar compensation. It is somewhat analogous to the manner in which ideal occlusion was established for the patient in Case Study 1 (Figure 1-5, *E*). **C,** Schematic showing a jaw disproportion characterized by maxillary deficiency and mandibular excess. Again, in this illustration normal occlusion is due to dentoalveolar compensation.

more upright (Figure 1-4). In both of these situations, the imperfect relationship of the jaws can lead to an almost infinite number of combinations of dental and skeletal compensations. This reflects Enlow's concept that all normal occlusions and orthodontic conditions stem from various compensatory alterations in the positions of the teeth and jaws.[39] Enlow's counterpart theory will be discussed in greater detail in the section on cephalometrics.

In short, nature tends to mask or camouflage skeletal discrepancies through counterpart compensations of the teeth and jaws. In addition, much of orthodontic treatment is simply directed toward completing nature's insufficient compensation. Case Study 1-1, page 49 is an excellent example of this concept (Figure 1-27).

Dental Occlusion and Oral Health

A hundred years ago, when orthodontics was in its infancy, the lofty though difficult goal of dentistry was to preserve the natural dentition for a lifetime. In one respect, the task was less formidable than it is today, given that the average life span in the United States at the turn of the twentieth century was approximately 30 years shorter than it was at the beginning of the twenty-first century. Until well into the twentieth century, after 20 or 30 years of age, mutilated dentitions were far more common than intact dentitions.

The leaders in dentistry at that time reasoned that the key to the preservation of an intact dentition was stable occlusion. The greatest threat to stable occlusion was tooth loss due to caries or periodontal disease (pyorrhea, as it was called then). It was commonly observed that loss of one or more permanent teeth caused adjacent and opposing teeth to migrate or drift in more or less predictable fashion, and it did not require remarkable insight to conclude that mutilated dentitions are unstable. Yet even mutilated dentitions ultimately acquired new stability, leading to the obvious conclusion that the dentition exists in a state of dynamic equilibrium.

Angle[38] proposed that the "science of occlusion" should become the basis for clinical dentistry, hoping that this would illuminate the factors responsible for stability or instability, and made the attainment of ideal occlusion as he defined it as the major goal of orthodontic treatment. Unfortunately, although the traditional concepts of "functional occlusion" and "balanced occlusion" in restorative and prosthetic dentistry have undoubted merit, in the intact natural dentition these terms have proved to be not only ambiguous but also largely fictitious. Even badly malposed teeth remain in a stable position, an observation that prompted Angle to assert somewhat facetiously, "There is nothing as stable as a malocclusion." This was a valuable insight, with an immediate application to an important problem: The early orthodontists observed that orthodontic tooth movement almost always led to some degree of occlusal instability. Relapse became an early part of the orthodontic lexicon. On the other hand, badly malposed teeth usually remain in stable positions. Hawley, a contemporary of Angle, is said to have quipped, "I would gladly pay half the fee to anyone who would manage the retention of my treated cases." A major reason for Angle's focus on ideal occlusion was his idea that if the occlusion were ideal, the teeth would be stable—and if the occlusion at the end of orthodontic treatment were not ideal, instability would be the inevitable result. The early orthodontists saw that even the most ideal occlusion as a treatment result did not guarantee long-term stability. It is clear now that a major factor in stability or instability is light but long-lasting pressure from the tongue versus the lips and teeth.[40]

Until fairly recently, it was thought that unstable occlusion promotes periodontal disease, which was a misinterpretation of cause and effect.[41–43] In fact, it is loss of periodontal attachment resulting from periodontal disease that causes teeth to drift, not vice versa. It was also believed that traumatic occlusion was a primary factor in causing periodontal problems; it is recognized now that occlusal trauma, if associated at all with a periodontal problem, is a secondary, not a primary, factor in its causation.

Another possible misinterpretation of the role of occlusion in oral health resulted from erroneous conclusions about the "high filling" effect. If a restoration is placed so that it creates a premature occlusal contact, the patient often develops tooth pain lasting days or even weeks. This finding supported the theory that faulty occlusion created *microtrauma,* a primary factor in causing pulpal hyperemia, as well as periodontal lesions. In orthodontics today, composite is often added to the occlusal surfaces of the posterior teeth temporarily to serve as mini-bite planes without patients complaining of dental pain. It is likely that pulpal hyperemia associated with a high filling is primarily the result of caries removal during tooth preparation for restoration with occlusal trauma being a secondary or compounding factor in causing pain.

The same type of misinterpretation of causality has been responsible for erroneous conclusions regarding occlusion and temporomandibular joint (TMJ) disorder (TMD).[44,45] It is now widely accepted that flawed occlusion is not a primary factor in causing TMD. In some individuals, occlusal prematurities can lead to the parafunctional habit of clenching or bruxing, thereby secondarily causing muscle spasm, fasciitis, or tendonitis resulting in pain in the region of the TMJ. But there is no evidence that any specific occlusal scheme within the normal range of variation fosters improved function (e.g., more efficient mastication) of the dentition with resultant improved oral or overall health of the individual. Of course, in mutilated dentitions there is clearly a loss of masticatory efficiency.[46] For a more detailed account of orthodontics and the patient with TMD, see Chapter 7.

Acknowledgment of these previous misunderstandings in no way alters the basic goals of orthodontic treatment, nor does it diminish the value of orthodontics in improving an individual's quality of life and social well-being. What it calls into question are some warmly held assumptions about the relationship of anatomical occlusion, oral function, and oral health. The traditional concepts of "functional occlusion" and "balanced occlusion" in restorative and prosthetic dentistry have undoubted merit, but in the intact natural dentition these terms are not only ambiguous at best and misleading at worst.

The Interaction of Function and Stability of the Dentition

The human dentition sustains two functions of biological significance: it has a central role in the masticatory system and plays a complementary role in anterior tooth display and the expression of emotion essential in social communication and social signaling.

In the first function, the teeth within and on opposing dental arches (i.e., the occlusion) bear direct physical loading during maturation, adulthood, and aging. Thus, occlusal function and occlusal stability, long viewed as discrete goals of orthodontic treatment, are, in reality, each part of the ultimate objective—to ensure the lifelong function, stability, and physiologic integrity of the dentition as an organ system.

Angle's assertion that intercuspation of posterior teeth is the major factor in tooth stability has proved to be incorrect. We know now that teeth are positioned in a state of equilibrium within the enveloping soft tissues. Indeed, during normal masticatory function the food bolus is prepared with no more than transitory occlusal contact during swallowing. On the other hand, occlusal contact does occur in almost everyone in brief clenching and grinding during rapid eye movement (REM) sleep, and some individuals have prolonged parafunction.

The true role of satisfactory proximal and occlusal contact of teeth in the natural dentition is to maintain balance within the organ system—that is, to ensure functional stability. In seeking occlusal stability in patients, the orthodontist is faced with two considerations, as follow.

First, it is important to differentiate between malocclusions that are functionally stable and those that are functionally unstable. Anatomical posterior crossbites, for example, vary in functional stability. If in a maxillary palatal crossbite the guiding cusps of the maxillary posterior teeth rest in the central fossae of mandibular posterior teeth, both occlusal function and tooth position may be quite stable and orthodontic correction is not indicated. On the other hand, conventional clinical wisdom is that any palatal crossbite that deflects the mandible on closure can be considered functionally unstable and therefore an indication for orthodontic treatment. In a maxillary buccal crossbite ("scissors bite"), at least some of the maxillary teeth are unopposed even if the patient shifts the mandible to one side. In Australian Aboriginals (who were renowned for their excellent occlusion and dental stability prior to the introduction of modern diets), such an arrangement is quite common and is compatible with normal masticatory function, oral health, and stability. However, severe Class II, Class III, or deep bite malocclusions tend to be functionally unstable because of the lack of coupling of anterior teeth and potential absence of antagonists for the terminal molars. For these patients, the occlusion may be a valid reason for treatment, although not necessarily a compelling reason in the absence of any concern by the patient about the psychosocial effects of impaired facial and dental appearance.

Second, it is also important to understand what aspects of occlusion are important in determining stability or relapse following orthodontic treatment. Will the establishment of interocclusal contacts between opposing teeth stabilize their vertical position? Almost certainly, yes, because even the intermittent pressures that accompany swallowing and REM sleep seem adequate to control vertical tooth migration so that it is no faster than vertical ramal growth. Will the occlusion stabilize a crossbite correction in which the maxillary arch was greatly expanded posteriorly or the position of maxillary incisors that were proclined excessively? Almost surely not, because light sustained force from stretched soft tissues will overcome the forces of occlusion of much shorter duration.

Perhaps the most simple and practical goal of orthodontics in regard to functional stability is the establishment of an effective occlusal platform to control eruption and vertical drift of teeth. In the anteroposterior and transverse dimensions, teeth must be placed entirely within the zone of equilibrium mediated by enveloping soft tissues. Thus, individual teeth or segments of a dental arch in functionally unstable positions or relationships may affect oral health adversely. This is what is implied in recognizing the existence of functional stability or instability. Making the distinction is an essential element of orthodontic assessment and most important in treatment planning.

When Angle proposed that the study of occlusion should become the core dental science, no one could have anticipated the dramatic advances that would occur in the basic medical sciences and technology over the following century, including insistence on scientific evidence for the validity of such advances. Whereas Angle was limited almost entirely to mechanical explanations for all occlusal phenomena, we now have the advantage of advances in biological anthropology and the molecular biology of tooth-supporting structures to help elucidate some of the still inadequately understood aspects of clinical orthodontics. Today, although the mechanism for postemergent tooth eruption is still incompletely understood, we know that the intermittent forces of occlusion cannot alone explain the relationship between occlusion and stability. The soft tissue equilibrium established by the tongue and lips and the transseptal fiber apparatus maintain stability of tooth positions.[40]

Bonwill and Angle believed that cusps, intercuspation, and the gearlike arrangement of articulated teeth were vital to their function. Their teleological reasoning was based on the idea that only the "Divine Architect" could possibly be responsible for such magnificently designed machinery. Both believed that tooth cusps and fossae serve as mini mortars and pestles for the trituration of food. They posited that the secondary function of cusps is to serve as locator jigs for referencing the upper and lower teeth, thereby maintaining their stability.

The flaw in their belief about the role of cusps in chewing and stability relates to several critical evolutionary events. The first of these events occurred 2.6 million years ago when the predecessors of modern humans (habilenes) first fashioned simple stone knives, which they used to slice through animal carcasses to obtain meat, which was eaten raw. What was not clear, at least until a recent theory emerged, is why *Homo erectus* had rather small jaws and small teeth, which were poorly adapted for eating raw meat. It is also notable that they had small mouth apertures with relatively small oral volumes. It is likely the explanation relates to discovery of and how to control and use fire. With the ability to control fire somewhere between 250,000 and 1 million years ago came the innovation of cooking food. Cooking food made eating and digestion more efficient, which in turn conserved an individual's energy.[47] Once humans began to cook, the requirement for tooth cusps to chew was greatly diminished. It is also clear from the archeological record that by the Stone Age, humans entirely wore the cusps off teeth through attrition by the time the permanent second molars erupted. A similar observation in Australian aboriginals prompted Begg, who had been a student of Angle's, to speculate that the sole purpose of tooth cusps in modern humans was to serve as jigs for guiding teeth into occlusion during dentitional development.[48] Begg speculated that once teeth were in occlusion, cusps no longer served a meaningful function.

Angle made a lasting contribution to dentistry by formalizing the concept that the lifetime preservation of the natural dentition requires establishing proximal and occlusal contacts of teeth to foster stability and equilibrium within the functioning dentition and achieving tooth positions that promote balance in the relationship of the dentition to its investing soft tissue and musculature. This disarmingly simple, yet ultimately profound, concept emphasizing the critical importance of functional stability of the dentition changed the future course of clinical dentistry. Tooth alignment and occlusion are important in maintaining the long-term function and appearance of the dentition, thus optimizing social well-being and quality of life, even if ideal interdigitation of teeth does not prevent postorthodontic relapse.

Perhaps Angle's most important contribution to clinical orthodontics was by providing the insight that the goals of treatment are to maintain or establish functional stability of the dentition and to achieve balance between dentition and soft tissue drape, thereby enhancing dentofacial appearance.

Epidemiology of Dentofacial Traits

The importance of an orthodontist knowing the convention of theoretically ideal occlusion and understanding the concept of normal occlusion should be obvious; however, what is not always as clear is the benefit of knowing the most typical variations in dentofacial traits in a population. This information can be derived from studying how widely the trait is distributed (prevalence) and the frequency with which it is found (incidence). It provides an important perspective for the practicing orthodontist when evaluating and advising potential patients regarding the desirability of treatment. In a population like Melanesian Islanders, where the incidence of "rocker jaw" is fairly high and as a result a skeletal Class III tendency is prevalent, correction of the attendant dentofacial characteristics may be less compelling for the orthodontist than if the individual were living in the United States.

This example is not meant to imply that because a dentofacial trait is common in a population, it de facto becomes more psychosocially acceptable. This is clearly not the case for many traits, and if it were true, far fewer orthodontists would be needed throughout the world! For instance, a maxillary midline diastema is a reasonably common finding and usually represents an entirely normal trait; yet many, if not most, individuals in the United States prefer to not have a diastema. Over the years, there have been a number of entertainers and people in the public eye who have proudly displayed "gap tooth grins." One of the most famous fashion models in the United States and an icon in the fashion industry for over 40 years has a significant maxillary midline diastema. Her photograph appeared on the cover of *Vogue Magazine* a record 27 times and her diastema was an important part of her signature smile. A similar photograph of an Australian fashion model appeared in *Sports Illustrated* in 2009 (Figure 1-5).

The example of midline diastema can also be used to demonstrate another benefit of knowledge derived from epidemiologic data in orthodontic evaluation and treatment planning. The incidence of maxillary diastemas 2 mm or greater in separate cohorts consisting of 8- to 11-year-olds, 12- to 17-year-olds, and adults 18 to 50 years old decreases steadily over this time interval. This finding supports the clinical observation that maxillary midline diastemas are often self-correcting. This is also true of anterior open bites.

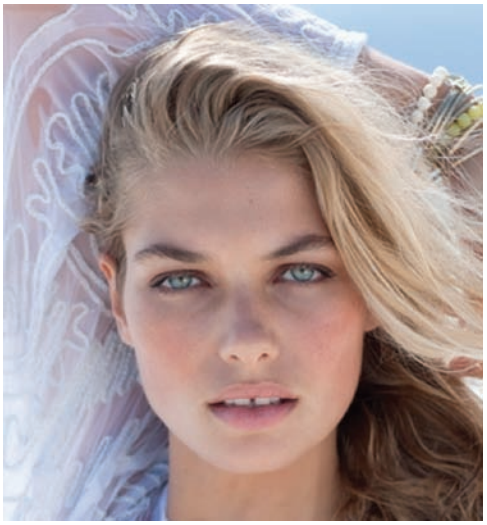


FIGURE 1-5 Jessica Hart, an Australian model, whose photograph appeared in *Sports Illustrated*. Her maxillary midline diastema does not appear to be hindering her career as a photographic model. Nonetheless, patients rarely, if ever, consult with an orthodontist and request a "gap-tooth grin."

Historically, because the characterization of dentofacial traits has been imprecise and often unreliable, there have been widely differing epidemiologic findings regarding the incidence and prevalence of normal occlusion and malocclusion. Until fairly recently, assessment of orthodontic treatment need was based largely on the degree of deviation of occlusal traits from the theoretical ideal. Studies in which any deviation from ideal occlusion was identified as malocclusion understandably gave skewed results indicating that as much as 95% of the population has some degree of malocclusion. If one uses the theoretical ideal as the standard, it is likely that less than 5% of the American teenage population has ideal occlusion.

National Health and Nutrition Examination Survey Data. Data from the third National Health and Nutrition Examination Survey (NHANES-III) provide a clear picture of malocclusion in the U.S. population in the 1990s.[33] The data are categorized as intra-arch traits and interarch traits.

Of the intra-arch traits, noticeable incisor crowding occurs in the majority of all racial and ethnic groups, with only 22% of adults having well-aligned lower incisors. Incisor irregularities are severe enough in 15% of the population that major effects on appearance and/or function are common, with major arch expansion or extraction of some teeth required for correction. With regard to interarch traits, about 20% of the population has deviations from the ideal bite relationship. In 2% the deviations are severe enough to be disfiguring and are at the limit for orthodontic correction. Less than 10% of the population has posterior crossbites, more than a 6-mm overjet, or more than 6 mm of overbite. Anteroposterior molar discrepancies of more than 6 mm occurred in 11% to 15% of the people surveyed.

If one calculates from the NHANES data the percentage of individuals who fall into Angle's three malocclusion groups, by far the greatest number are of Class I (50% to 55%). The next highest group are of Class II (15%), and the smallest number are of Class III (less than 1%). The remainder of the sample had normal occlusion (30%). It should be made clear that the percentage of patients in each Angle category found in a typical orthodontic practice is considerably skewed from this general population data.

Index of Treatment Need as an Estimate of Treatment Need. Dentofacial appearance and associated psychosocial issues, not just the way teeth fit together, play a role in defining orthodontic treatment need. For this reason, determining treatment need just from an examination of dental casts or radiographs is difficult at best. Brook and Shaw[49] in the United Kingdom developed a scoring system for malocclusion, the Index of Treatment Need (IOTN), which places patients in one of five grades ranging from “no need for treatment” (1) to “treatment required” (5). The IOTN has two components: dental health (based on deviations from ideal occlusion) and esthetic concerns (based on the way patients identify themselves relative to a graded set of photographs of malocclusions). As might be expected, a high correlation exists between scores on the two components of the index, which provides some confidence in using the dental health component alone as an indicator of treatment need. A consensus panel of orthodontists established the significance of various occlusal discrepancies, and the IOTN grades seem to reflect clinical judgments better than previous methods.

Applying the IOTN to the survey data indicates that 57% to 59% of each of the racial and ethnic groups has at least some degree of orthodontic treatment need. More than 30% of white youth, 11% of Hispanic youth, and 8% of black youth report receiving treatment. Severe malocclusion is observed as or more frequently in Hispanics or blacks, so these percentages reflect a lower level of treatment in those groups, not a lower treatment need. Treatment is much more frequent in higher-income groups, but 5% of the lowest-income group and 10% to 15% of intermediate-income groups report being treated. Although all states are now required to include orthodontic services as part of their Medicaid programs, which in itself is testimony to the importance of overcoming severe orthodontic problems, less than 1% of orthodontic patients have their treatment covered through social programs. Despite this, nearly 10% of the adolescents in the lowest-income groups and 15% of those in modest-income groups now report receiving orthodontic treatment. Even families with modest resources often give orthodontics a high priority because of its role in improving social well-being and a person’s social potential in life, as well as quality of life. Nevertheless, because there is so little evidence of an oral health or general health benefit from orthodontic treatment, both Germany and Sweden have recently eliminated orthodontics from their National Health Services.

Etiologic Considerations: Hereditary versus Environment

Tooth irregularities and jaw disproportions are developmental conditions resulting from a combination of genetic, epigenetic, and environmental factors. In most instances, malocclusion and dentofacial deformity are caused not by some pathologic process but by moderate distortions of normal development due to intrinsic and extrinsic factors. Occasionally a single specific cause is apparent; for example, an anterior open bite in the early transitional dentition may result from thumbsucking. A more dramatic example of a condition arising from extrinsic causation is mandibular asymmetry secondary to a subcondylar fracture of the jaw in childhood. In some craniofacial syndromes, characteristic malocclusions develop from the influence of multiple genes. More often, deviations from normal occlusion result from a complex interaction among many factors that influence growth and development, and it is impossible to describe a specific etiologic factor. The major weakness of all current classifications of malocclusion is that they totally ignore etiology.

Fundamental to good taxonomy, the science of classification, is the concept that etiology should be included in any classification. In orthodontics, we can say that there are environmental and hereditary factors in the etiology of malocclusion or, stated another way, that genotype plus epigenetic and environmental factors yields the phenotype. Regrettably, the fact is that often we are not able to ascertain which malocclusions are largely determined on a genetic basis or epigenetic basis, which are caused largely from environmental factors, and which of the problems we are dealing with are the result of a combination of all of these factors. One of the most exciting aspects of the biological basis of orthodontics today is related to advances in genetics in the genomic era. The latest information regarding the role of genetics in the etiology of orthodontic conditions is addressed in Chapter 5 of this volume.

For an examination of etiologic factors for malocclusion under three major headings, specific causes, hereditary influences, and environmental influences, we refer the reader to Chapter 5 in *Contemporary Orthodontics*.[1]

Limitations of Orthodontic Treatment

Envelope of Discrepancy. One of the most important concepts for a beginning orthodontic resident to grasp is the range of tooth movement that can be accomplished within the biological limits of the system. Thus, it is the orthodontist’s task in diagnosis and treatment planning to ascertain an individual’s available limits of bone and soft tissue adaptation, given the dental and skeletal changes that the orthodontist and patient would like to accomplish. Of course the required range of tooth movement for a patient is determined by the nature and severity of the orthodontic problem. This determines the amount and direction of needed tooth movement and, in turn, the mode of orthodontic intervention that will be necessary to accomplish it. We have called the theoretical boundaries of the potential range of tooth movement the *envelope of discrepancy* (Figure 1-6, *A*–*C*).

The envelope can be thought of as an elastic three-dimensional, asymmetric closed container. Orthodontics alone rearranges the contents of the container; orthopedic-functional treatment and surgical treatment change the shape of the container. For any characteristic of malocclusion, four ranges of correction exist: (1) an amount that can be accomplished by orthodontic tooth movement alone; (2) a larger amount that can be accomplished by orthodontic tooth movement aided by absolute

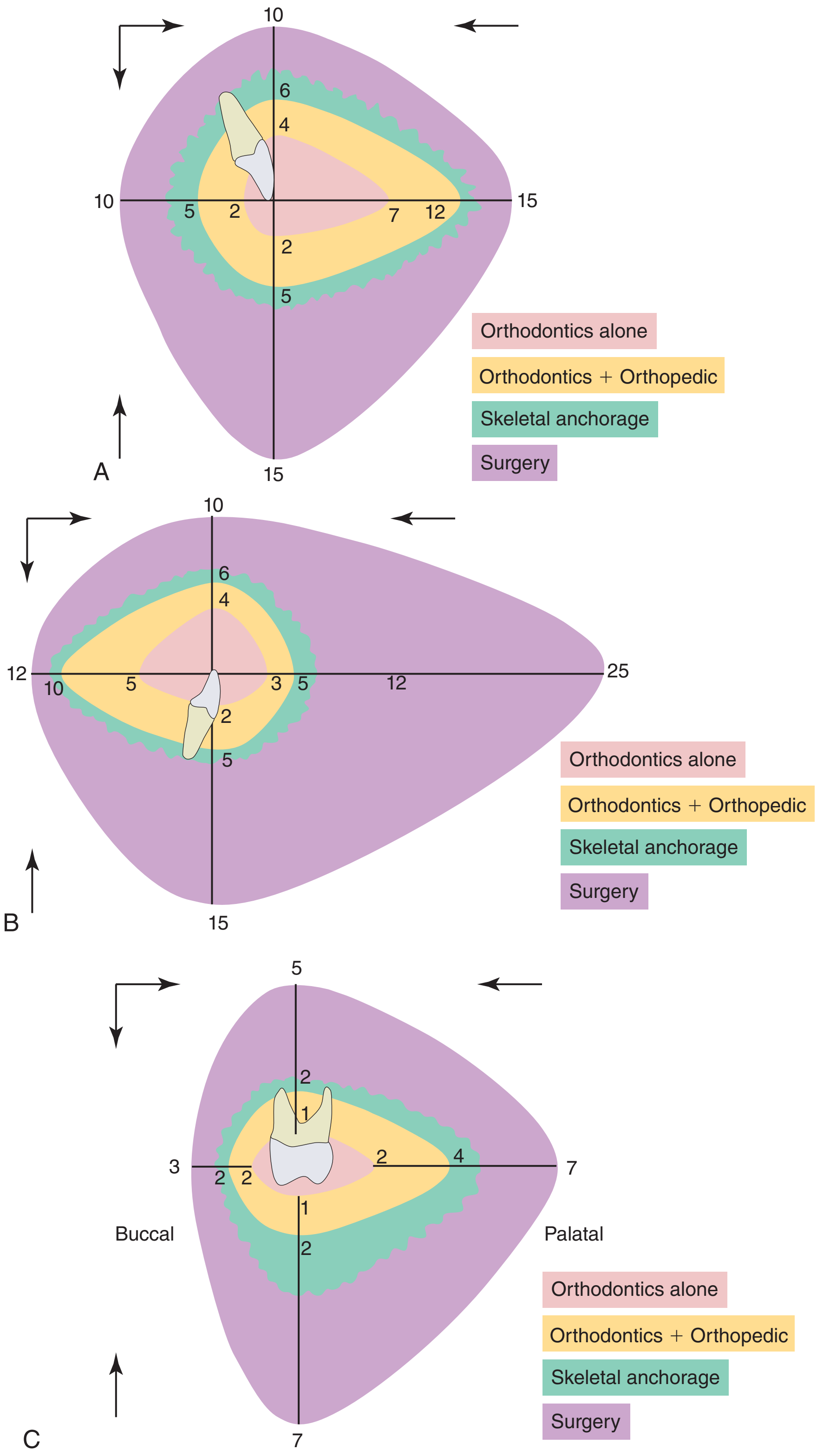


FIGURE 1-6 A–C, The anteroposterior, vertical, and transverse millimetric range of treatment possibilities in orthodontics can be expressed as an envelope of discrepancy. What is meant by treatment possibilities is the amount of tooth movement that can be accomplished by orthodontics alone, orthodontics plus dentofacial orthopedics with or without skeletal anchorage, or orthodontics plus orthognathic surgery. The different colored zones describe the range of potential tooth movement. The *arrows* designate the direction of the movement in the diagram. The *pink zone* represents the envelope for orthodontics alone, the *yellow zone* depicts orthodontics plus orthopedics, the *green zone* shows skeletal anchorage, and the *blue zone* shows any combination of these zones with orthognathic surgery. The reason the green zone is shown in "fuzzy" fashion is that there are sufficiently reliable data only to make estimates at this point. The same limitation is the reason there is no figure depicting the mandibular transverse envelope.

anchorage (bone anchors); (3) an additional amount that can be achieved by functional or orthopedic treatment to modify growth; and (4) a still larger amount that requires surgery as part of the treatment plan. Thus, if a patient presents with overjet of 7 mm, attributable to forward position of the maxillary incisors, the correction of the overjet is just within the range of orthodontic tooth movement, most likely after maxillary premolar extractions (maxillary first premolars on average are 7.5 mm in width, potentially allowing that amount of retraction). If the maxillary incisors required 12 mm of retraction, it would require orthodontic tooth movement and, in addition, an attempt to redirect facial growth with dentofacial orthopedics with or without skeletal anchorage. As a hypothetical, to retract the maxillary incisors 15 mm would require a combination of orthodontics and orthognathic surgery. The reason it is hypothetical is there is little chance an orthodontist would ever want to retract the maxillary incisors this far. Nonetheless, the same rationale applies to assessing the transverse and vertical possibilities of orthodontic treatment. With the availability of tooth extractions, TADs, and orthognathic surgery, there is little excuse today for an orthodontist to allow a treatment philosophy or an appliance system to largely dictate a treatment plan or establish the final positions of the teeth. By the same token, just because the tooth movement is feasible should not tempt an orthodontist to establish it as a treatment goal simply as a challenge. Instead, treatment goals should take into consideration numerous factors, not least of which is dentofacial esthetics.

In general, orthodontic and orthodontic-functional treatment can create larger sagittal plane (anteroposterior discrepancies) corrections than they can in the vertical or transverse planes. The orthodontist has greater latitude for correcting maxillary protrusion than mandibular protrusion because of anatomic and physiologic constraints.

Timing of treatment also is a factor in the amount of change that can be produced. The amount of tooth movement that is possible is about the same in children as it is in adults. However, the orthopedic-functional range diminishes steadily as a child matures and disappears after the adolescent growth spurt, so some Class II and Class III conditions that could have been treated in a growing child with growth modification and tooth movement require surgery. Controlling excessive vertical growth in children is difficult, and TADs can be useful for this in older patients.

Soft Tissue Limitations. Until fairly recently, orthodontic diagnosis and treatment planning were based on hard tissue relationships and on the Angle paradigm that considered ideal dental occlusion "nature's intended ideal form." In this view, the clinician and nature are partners in seeking the ideal. In the modern biological model, variation is accepted as the natural form. Ideal occlusion is the exception rather than the rule, and the orthodontist and nature are often adversaries. The orthodontist's task is to achieve the occlusal and dentofacial outcomes that would most benefit the individual patient, whose concerns with appearance are paramount. Because the soft tissues largely determine the limitations of orthodontic treatment, from the perspective of functional stability as well as appearance, the orthodontist must plan treatment within the patient's limits of soft tissue adaptation and soft tissue contours.[50] This concept requires greater emphasis on soft tissue function and dentofacial appearance during the clinical examination.

In the current broader view in dentistry and orthodontics, what is best for a patient regarding functional stability of the dentition and dentofacial appearance is not necessarily a theoretical and highly idealized concept of ideal occlusion. The orthodontist's task is to achieve the occlusal and dentofacial outcomes that will most benefit the patient. This goal must be accomplished within the bounds of the individual's ability to adapt physiologically to the morphologic changes that have been rendered. In a sense, all orthodontic treatment outcomes are a compromise between the orthodontist's wishes and nature's demands, particularly in the long run. It has taken a century, not necessarily to learn but to accept that it is the soft tissues that largely determine the limitations of orthodontic correction. Orthodontists have traditionally viewed hard tissue structural discrepancies as the major limitation of treatment. In reality, it is the soft tissues that more closely determine how successfully dentofacial traits can be modified.

Limitations in orthodontic treatment related to the soft tissues include (1) pressures exerted on the teeth by the lips, cheeks, and tongue; (2) limitations of the periodontal attachment; (3) neuromuscular influences on mandibular position; (4) the contours of the soft tissue facial mask; and (5) lip–tooth relationships and anterior tooth display during facial animation. The physiologic limits of orthodontic treatment (i.e., the ability of the soft tissue to adapt to changes in tooth and jaw positions) are often narrower that the anatomic limits of treatment. In the correction of an orthodontic condition in a growing patient, or with the use of TADs in a nongrowing patient, it is not unusual to produce a change of 7 to 10 mm in molar relationship, overjet, or overbite. Yet the tolerances for soft tissue adaptation are often less than half this amount. For instance, in expansion of the lower arch, the envelope is more like 2 to 3 mm, and it is even less for changes in condylar position.

In some ways, orthodontists had it backward for 100 years. Nature does not intend for the orthodontist to achieve perfection but rather contends with the orthodontist trying to achieve perfection. Treatment "failures" are generally the result of poor treatment response rather than of inadequate treatment, and to a great extent treatment response is also determined by the soft tissues.

Rather than designating orthodontic outcomes as successes and failures, it is more logical to categorize patients as "responders" and nonresponders. Similarly, since posttreatment "relapse" is determined by physiologic adaptation and any subsequent growth, postretention patients should be characterized as adapters and nonadapters. Using this construct, the orthodontic treatment population can be represented by a bell-shaped curve, with the most favorable responders and adapters at one end and the most unfavorable at the other end. For the most part, patients who are presented at meetings as the most dramatic successes and failures are merely the outliers on a normal distribution curve. Any individual's position on that curve will be determined, to a great extent, by soft tissue influences on the treatment process and outcome.

Benefits, Risks, Burden, and Prognosis of Treatment

It is the orthodontist's obligation to determine the maximum expected value from orthodontic therapy and the minimum expected loss, or to calculate benefit versus risk for each patient, with both benefit and risk including psychosocial factors. One often has to consider separately what is the best treatment for the malocclusion and what is the best management of the patient (including the burden of treatment). These are not always compatible. Because of our limited understanding of the etiology and nature of malocclusion, the answers to these questions are usually based on probabilities. What is the probability, if there is no treatment, that ill effects will result from the malocclusion? What is the probability, if treatment intervenes, that it will be successful and the result stable? What is the probability, if treatment is instituted, that such hazards and risks of orthodontics as root resorption, decalcification, or devitalization will occur? Will the impact of orthodontic treatment on the patient's personality development be favorable or unfavorable? These questions all relate to prognosis. They require estimates even if definitive answers are not possible.

A more conventional approach to the cost-benefit aspect of orthodontics is the consideration of the indications and contraindications for treatment. Indications for treatment have already been discussed, but the orthodontist should not underestimate the contraindications for treatment. They are, in addition to cooperation problems, the susceptibility to the other hazards of orthodontic treatment—that is, root resorption, decalcification, devitalization, fenestrations or dehiscences of alveolar cortical plate, or general alveolar bone loss. Of course, another contraindication to treatment is poor modifiability or a great risk of relapse.

Today, another major task for the orthodontist in treatment planning is to estimate the effectiveness and efficiency of possible treatment plans so that the best combination of these important factors can be selected. This determination is the research goal of both careful retrospective studies of treatment outcomes and randomized prospective clinical trials when these are possible. For example, the now classic Class II clinical trials of recent years, which studied the response to early (preadolescent) versus later (adolescent) treatment, showed that despite some individuals profiting significantly from early treatment, on average there was no significant difference in outcome between early two-stage and later one-stage treatment. Does that mean there should be no preadolescent Class II treatment? Of course not. It does mean that patients should be selected for preadolescent treatment for problems specific to that individual child. Relying on these types of data is what is meant by "evidence-bolstered orthodontics."

DIAGNOSIS

Overview of the Problem-Oriented Approach

Decision-making in orthodontics requires the establishment of a prioritized problem list before considering treatment options. In this method, the prioritized problem list becomes the "diagnosis" (Figure 1-7). Essential to the establishment of a complete problem list is the creation of an adequate database. The elements of the database are:

1. Questionnaire and interview data
2. Clinical examination data including the systematic description of the patient's dentofacial traits (classification)
3. Data from diagnostic records

The problem list is derived from the database and is prioritized. Tentative solutions are then proposed for the

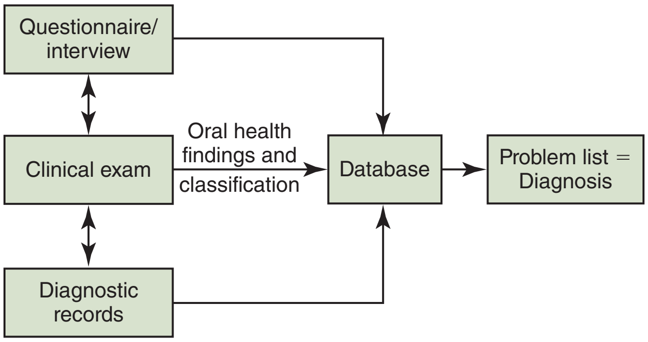


FIGURE 1-7 This flow chart shows the elements of the database and how a problem list is derived from the database. What has changed in recent years is that it is no longer considered necessary to have "complete" orthodontic records before systematically describing the patient's orthodontic condition. Today, the systematic description (i.e., classification) is accomplished during the clinical examination.

individual problems. Favorable or unfavorable interactions among the tentative solutions are considered, and one or more alternative unified treatment plans are synthesized. The alternatives are presented to the patient and/or parent, and with their input, an individualized treatment plan and mechanotherapy are established (Figure 1-8).

Goals of Modern Orthodontic Assessment

Diagnosis in medicine and dentistry is the process of identifying the nature and cause of an illness or malformation (something potentially harmful to the individual and thus a problem). In medical diagnosis, one attempts to understand the nature of a disease or disease process through observation, interpretation, and labeling or symbolization. Disease manifestations are signs that can be objectively seen or measured by the doctor and subjective symptoms that the patient can report. Underlying a patient's signs and symptoms are physiologic or pathologic processes that are triggered by etiologic or causative factors.

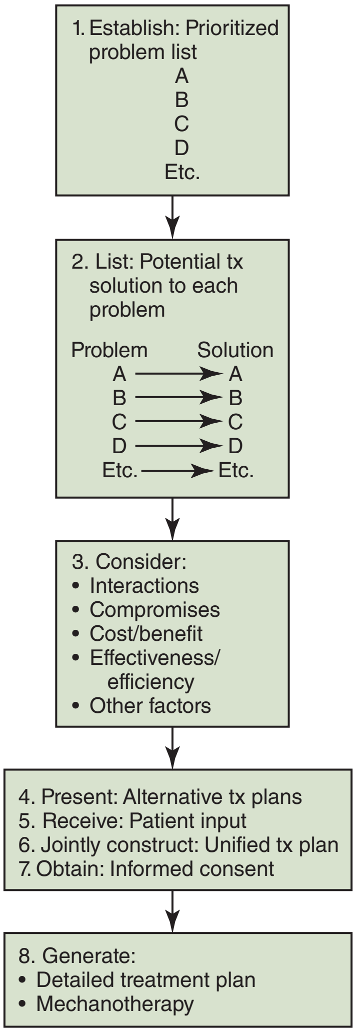

1. Establish: Prioritized problem list
A
B
C
D
Etc.
2. List: Potential tx solution to each problem
Problem
Solution
A
A
B
B
C
C
D
D
Etc.
Etc.
3. Consider:
• Interactions
• Compromises
• Cost/benefit
• Effectiveness/ efficiency
• Other factors
4. Present: Alternative tx plans
5. Receive: Patient input
6. Jointly construct: Unified tx plan
7. Obtain: Informed consent
8. Generate:
• Detailed treatment plan
• Mechanotherapy

FIGURE 1-8 This flow chart outlines the eight steps that must be taken from the time a prioritized problem list is established to when a detailed treatment plan and mechanotherapy are generated. The essential components of the process are (1) being sufficiently careful to not overlook any aspect of the problem, (2) taking enough time to solicit patient/parent input, and (3) being certain that the patient/parent decision is an informed one. The number of visits required to accomplish these eight steps is determined by the complexity of the orthodontic condition and the orthodontist's practice management style.

Typical orthodontic conditions, as seen in everyday practice, are rarely the result of illness or malformation, and rarely does a patient complain of symptoms associated with occlusal disharmony. Therefore, the term "diagnosis" is not a totally appropriate description of the orthodontic evaluation process. "Orthodontic assessment" is a far more accurate term. The use of the word "problem," as in establishing the orthodontic problem list, has a different connotation than its use in other specialties of dentistry and medicine. A problem in orthodontics is not necessarily harmful but is simply one or more dentofacial traits that are undesirable and need to be brought closer to the theoretical ideal.

Perhaps an even more difficult condition of orthodontic assessment is the fact that some of our standards in orthodontics are culturally imposed. The importance that people place on their teeth from an esthetic point of view requires a value judgment on the part of the orthodontist. It has been shown that the esthetic standards of the public do not always correlate with accepted esthetic guides for orthodontists. The choice of treatment in orthodontics depends to some extent on social, ethical, and economic factors regarding the patients, their families, and the society in which they live. When the clinician is forced to make esthetic and ethical judgments about a fundamentally biologic problem, he or she is invoking art, not science, and the final decision should represent wisdom, not necessarily truth in a scientific sense.

If all patients presented for orthodontic evaluation in the fourth decade of life, the decision-making process (diagnosis and treatment planning) would be a relatively straightforward matter. The variables that would have to be evaluated and correlated would be occlusion, dentofacial appearance and self-image, and function (physiologic adaptation). Because most patients are still growing when an orthodontist evaluates them, it is necessary to try to anticipate changes that will occur in occlusion, dentofacial appearance/social well-being, and function/physiologic adaptation—which can be done only with a high degree of uncertainty.

The more systematically an orthodontist approaches the collection of adequate diagnostic data, and the more thoroughly he or she interprets these data in terms of expected treatment responses, the better will be the probabilities for successful correction. At the same time, it is necessary to keep in mind the inherent uncertainties in the diagnostic process so that there is no reluctance to adapt treatment to meet an unexpected turn of events.

Concepts of Diagnosis in Orthodontics

The concept of diagnosis in orthodontics has been interpreted in several ways and thus the term diagnosis has been used by different authors to mean different things. Some orthodontists use the term "diagnosis" in a rather narrow sense, focusing on variations in dental occlusion that would need correction in order to obtain ideal occlusion. Those who subscribe to this limited definition of diagnosis prefer to call the reasoning process needed to determine the treatment strategy simply "case analysis." This could be called the "traditional" approach because it was made popular by Angle. In Angle's view, normal occlusion, favorable function, and acceptable dentofacial esthetics represented an identity, and it was not possible to have one without the others. Ideal occlusion brought about perfect harmony and balance in function and appearance. This view included physiologic adaptation, because forces from occlusion were thought to stimulate alveolar bone formation and, in turn, periodontal health and tooth stability. The proper force directions would be obtained only if the occlusion were ideal. Of course, today we know from vast clinical experience that these concepts are incorrect.

Early critics of the "traditional" diagnostic approach insisted that classification of malocclusion was not a substitute for diagnosis and that proper diagnosis constituted the establishment of the true nature of the orthodontic problem. The concepts of dental and skeletal components to malocclusions can be credited to these critics. They challenged Angle's idea of the constancy of position of the maxillary first molars and pointed out that in planning treatment for a patient with, for example, Class II, division 1 malocclusion, it is necessary to ascertain whether the maxillary teeth are positioned too far anteriorly, the mandibular teeth are positioned too far posteriorly, the maxilla is prognathic, the mandible is retrognathic, or any combination of these factors. This approach to diagnosis can be called the "rational" approach. As orthodontics evolved as a modern specialty, practitioners began to realize that psychosocial factors are often of equal importance to the structural and functional characteristics of an orthodontic problem. In other words, one must consider the whole individual, not just their dentofacial characteristics.

Classification as a Diagnostic Tool

Development of the Angle Classification. Carabelli, in the mid-nineteenth century, was probably the first to describe in any systematic way abnormal relationships of the upper and lower dental arches.[51] The terms "edge-to-edge bite" and "overbite" are actually derived from Carabelli's system of classification. The term "orthodontics" (*orthodontosie*) was coined by Lefoulon of France at approximately the same time as interest in these problems became widespread.[52] Even though several treatises on orthodontics had already been written by the beginning of the twentieth century, these authors had no acceptable method for describing irregularities and abnormal relationships of the teeth and jaws.

Arguably the most seminal idea in the history of orthodontics is the concept regarding the line of occlusion and its role in describing theoretically ideal anatomic occlusion. Bonwill was the first to use the term "line of occlusion" in describing the more or less elliptical arc formed by the buccal cusps of the mandibular posterior teeth and the incisal edges of the mandibular anterior teeth. When the maxillary and mandibular teeth are in contact, the line of occlusion cannot be visualized; however, when a patient smiles, the facial incisal aspects of the teeth can be seen. A curved line following the facial incisal edges of the maxillary teeth has been called the "esthetic line of the dentition."[53] The orientation of the esthetic line of the dentition has become an important descriptive characteristic of occlusion and malocclusion, from both an appearance and a functional standpoint. The anterior portion of the esthetic line of the dentition is called the "smile arc,"[54–56] which will be discussed in Chapter 2. Angle contributed the concept that if the mesiobuccal cusp of the maxillary first molar rests in the buccal groove of the mandibular first molar and if the mandibular line of occlusion is consonant with the central fossa line of the maxillary teeth, ideal occlusion would result (Figure 1-9). Surely, equally as brilliant as the concept of the line of occlusion was Angle's observation that the anteroposterior relationships of the permanent first molars are the keys to occlusion. Based on these criteria, Angle described three basic types of malocclusion, all of which represented deviations in an anteroposterior dimension (Figure 1-10). Lischer[57] later termed Angle's Class I occlusion "neutro-occlusion," his Class II relationship "disto-occlusion," and his Class III relationship "mesio-occlusion." The Angle classification was readily accepted by the dental profession, because it was simple and brought order out of what previously had been confusion regarding dental relationships.

The Rise and Fall of Gnathostatics

It was recognized almost immediately, however, that there were deficiencies in the Angle system. In 1912, a report to the British Society for the Study of Orthodontics suggested that malocclusions be classified with regard to deviations in the transverse dimension, the sagittal dimension, and the vertical dimension.[58] Critics also pointed out that Angle's method disregarded, both in classification and in treatment planning, the relationship of the teeth to the face.[59] Simon[60] with his system of "gnathostatics" used a facebow transfer and mounting to relate the dental models to the rest of the face and cranium in all three dimensions of space. Van Loon[61] and Simon were the first to relate the teeth to

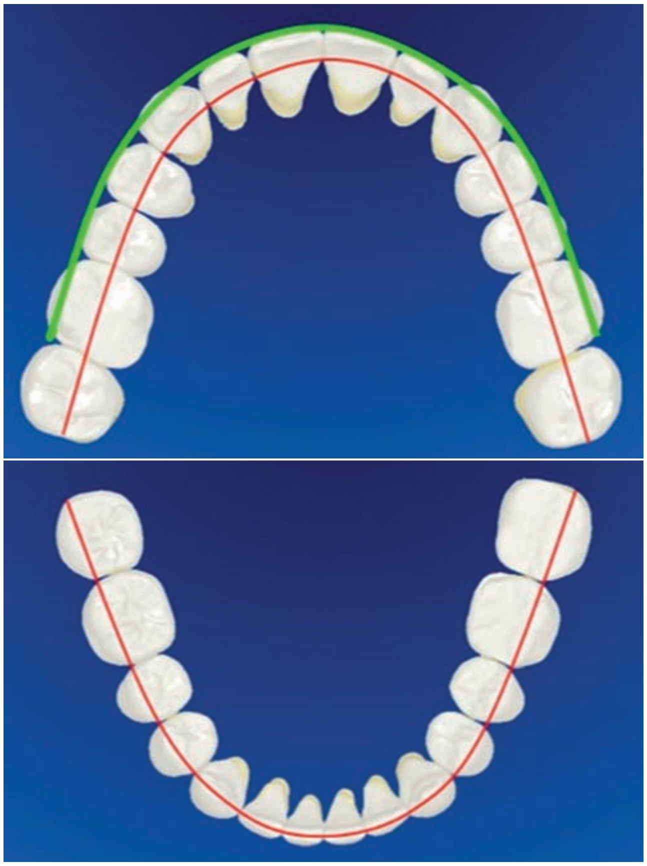


FIGURE 1-9 Bonwill and Angle proposed that if the buccal occlusal line of the mandibular teeth coincided with the central fossae line of the maxillary teeth, ideal occlusion would result. The only recent addition to this concept is that from an appearance point of view, the line corresponding to the line of occlusion that one sees when an individual smiles is the facial occlusal line (the esthetic line of the dentition), which is shown in *green.* The anterior segment of the esthetic line of the dentition is called the smile arc.

the face in this fashion. Simon's approach, although somewhat cumbersome, clearly represented an advance. Simon used the Frankfort plane (described by a line from porion to orbitale) and a perpendicular line to Frankfort was constructed at orbitale. He called this line the "orbital plane." The maxillary model was then scribed with a line corresponding to the orbital plane (Figure 1-11).

Simon believed that in normal occlusion, the orbital plane passes through the distal third of the maxillary canine. He further posited that in disto-occlusion, if the maxillary canine was farther forward than this line, it was the maxillary problem, and if the canine was correctly positioned in relationship to the orbital plane, then the anteroposterior problem could be assumed to be a problem of mandibular retrognathism. Simon's facial reference line (the orbital plane) was in contradistinction to Angle's skeletal reference, which was the key ridge (the lowest extent of the zygomaticomaxillary suture). Angle believed that the mesiobuccal root and cusp of the maxillary first molar in ideal occlusion was directly below the key ridge. It did not take long for both these flawed concepts to be abandoned by the rest of the specialty.

If it had not been for the introduction of roentgenographic cephalometrics in the 1930s and 1940s,[62] gnathostatics probably would have made a more lasting impact on orthodontics. With the advent of the lateral cephalogram, many of the relationships that could be determined from gnathostatic casts could more easily be observed on the cephalometric head film. Arguably, radiographic cephalometrics, although an important milestone in the evolution of orthodontics, has in many ways hindered viewing the teeth and jaws as a three-dimensional issue.

Other Problems with the Angle Classification

As orthodontic treatment became more widespread and treatment possibilities other than arch expansion were considered, several other problems with the Angle classification emerged, all of which revolved around its narrow focus on the dentition and absence of a diagnosis that points logically to a treatment plan.

This difficulty becomes apparent when it is recognized that malocclusions having the same Angle classification may, indeed, be only *analogous* malocclusions (having only the same occlusal relationships) and not necessarily *homologous* (having all characteristics in common). Despite the informal additions to Angle's system that most orthodontists use, there is a tendency to treat malocclusions of the same classification in a similar manner. Homologous malocclusions require similar treatment plans, whereas analogous malocclusions may require different treatment approaches. Some poor responses to treatment are undoubtedly related to this fault in diagnosis.

Figure 1-12 illustrates two nearly identical Angle Class II, Division 1 malocclusions in children of the same age. There are differences in skeletal proportions and in the relationships of the teeth to their respective jaws, both of which affect the profile. Individual orthodontists may differ concerning treatment plans, but the two cases should not be treated exactly the same. These are analogous malocclusions. For one, an effort has to be made to retract the maxillary teeth without further proclining the mandibular incisors. For the second patient, proclining the mandibular incisors might be justifiable and interarch Class II mechanics could probably retract the maxillary teeth, while proclining the mandibular teeth.

Because Angle and his followers did not recognize any need for the extraction of teeth, the Angle system does not take into account the possibility of arch-perimeter problems. The reintroduction of extraction

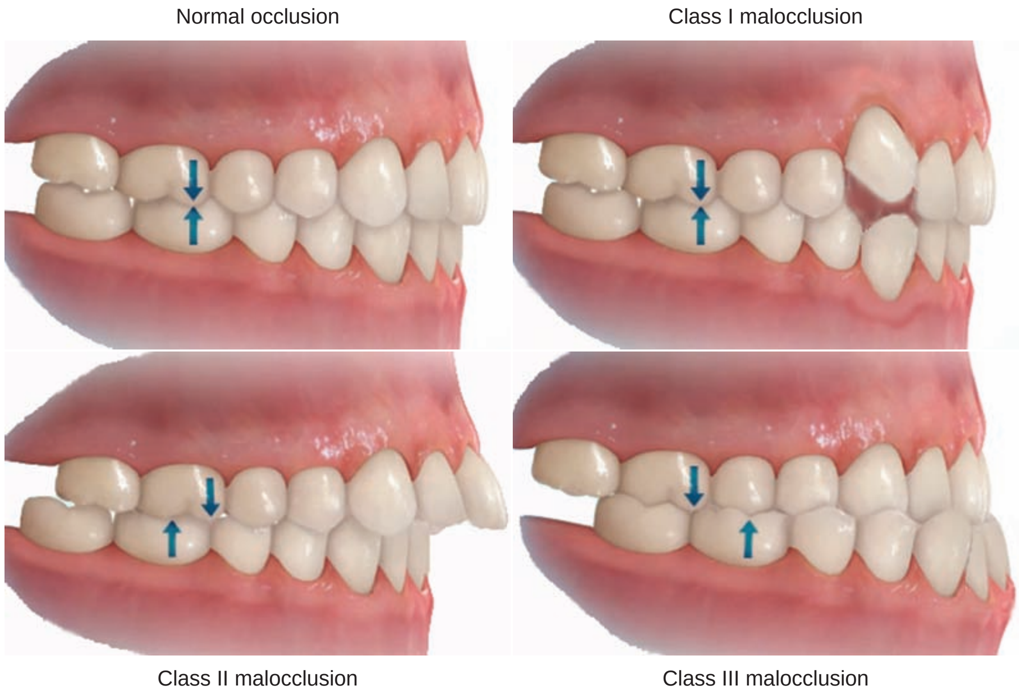


FIGURE 1-10 Angle suggested that in ideal occlusion the mesiobuccal cusps of the maxillary first molars should rest in the buccal grooves of the mandibular first molars. He called the permanent first molars the keys to occlusion and designated this ideal molar relationship Class I. He observed that two variations of this molar relationship exist, and he designated these Class II and Class III. Subsequently, the relationship of the canines also became part of the description of Class I, II, and III probably as a result of Simon's influential but erroneous belief that the maxillary canines were the keys to occlusion. Nonetheless, the maxillary canines should ideally fit in the embrasures between the mandibular canines and first premolars.

into orthodontic therapy has made it necessary for orthodontists to add arch-perimeter analysis as an additional step in classification.

A final, but not inconsequential, difficulty with Angle's classification procedure is that it does not indicate the complexity and severity of the problem.

It is for these reasons that we advocate systematically enhancing the Angle classification by describing the five major characteristics of malocclusion.

Systematic Description: Ackerman-Proffit Classification (the Orthogonal Analysis)

To overcome the difficulties just discussed, we recommend using a classification scheme in which five or fewer characteristics and their interrelationships are assessed.[63,64] A complex of interrelated variables, as encountered in many orthodontic conditions, may be represented most conveniently through the use of sets. Venn proposed this representation in 1880, and his idea has become prominent in symbolic logic for computer use. The set theory deals with collections or groups of entities and it represents the relationships between these groups by graphic patterns. A Venn diagram offers a visual demonstration of interaction or overlap among parts of a complex structure. A collection or group in this system is defined as a set, and all elements contained in a set have some common property.

There are two major components to this classification scheme: (1) dentofacial appearance and (2) spatial relationships of the teeth and jaws. Although describing only five or fewer major characteristics of any orthodontic condition is needed to fully portray the situation, there are several other factors that must be considered before arriving at these five descriptors. The other factors are listed as follows:

1. Dentofacial appearance
   - Facial symmetry/vertical proportions
   - Anterior tooth display
   - Orientation of the esthetic line of occlusion in NHP (natural head position)
   - Profile considerations
2. Spatial relationships of the teeth and jaws
   - Arch alignment and symmetry
   - Anteroposterior characteristics
   - Transverse characteristics
   - Vertical characteristics
   - Orientation of the occlusal plane in NHP

The five or fewer descriptors needed to describe any orthodontic condition are:

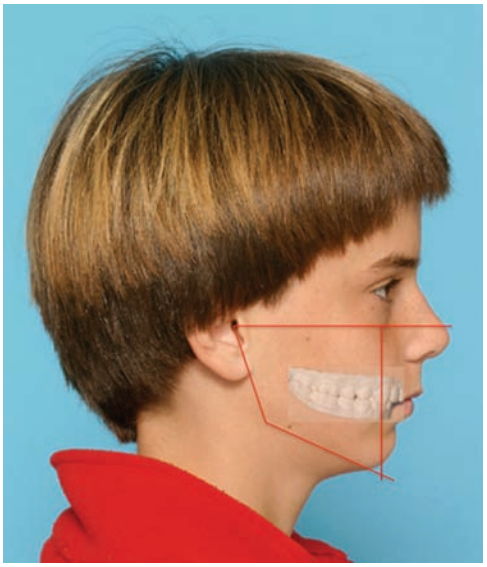


FIGURE 1-11 This is a modern-day illustration of Simon's concept of gnathostatics and the law of the orbital plane. It was the first realistic attempt to relate the dentition to the face. According to Simon, the orbital plane (a perpendicular to Frankfort horizontal at orbitale) in a patient with normal occlusion would pass through the distal third of the maxillary canine. Simon's theory was later shown to be flawed, but it forever changed orthodontists' outlook regarding dentofacial balance.

1. Facial appearance, anterior tooth display, and the esthetic line of the dentition
2. Alignment, arch form and symmetry
3. Anteroposterior relationships
4. Vertical relationships
5. Transverse relationships

To fully describe the position and orientation of the dentition in the facial skeleton and its relationship to the facial soft tissues is exactly analogous to what is necessary to describe the position of an airplane in space (i.e., translation [forward/backward, up/down, right/left]), which must be combined with rotation about three perpendicular axes (yaw, pitch, and roll) (Figure 1-13). In engineering terminology, the object has 6 degrees of freedom. In orthodontics, introduction of the rotational axes into the description of dentofacial traits (and orthodontic problems) improves significantly the precision of the description and therefore facilitates development of the problem list (Figures 1-14 and 1-15). Many patients present with anteroposterior problems, yet most of these individuals have some type of vertical problem as well. Our representation of the interaction of the five major characteristics of malocclusion in which both the translational and rotational components are combined in a single diagram is shown in Figure 1-16. Common to all dentitions is their effect on anterior tooth display and the soft tissue drape. We represent this as the framework or "universe" within which all other deviations from the theoretical ideal reside.

Also common to all dentitions is the degree of alignment, arch form, and symmetry of the teeth within the dental arches. For this reason, alignment, arch form and symmetry are represented within the overall framework represented by the face and smile. In regard to tooth alignment, arch form, and arch symmetry, any deviation from the line of occlusion is described and included in this collection of possible discrepancies.

If the teeth are perfectly aligned in both arches, by definition ideal occlusion will occur when the mesiolingual cusps of the maxillary first molars rest in the central fossae of the mandibular first molars, provided the curves of Spee are harmonious and there is no tooth-size discrepancy. This, of course, is the original Angle concept. There are patients who have anteroposterior deviations from the ideal yet have normal transverse and vertical relationships. There are also patients who have vertical deviations from the ideal, such as anterior open bite, yet have normal sagittal and transverse dimensions. More often one finds patients who have both sagittal deviations and vertical deviations such as Class II, Division 1 with deep anterior bite. The same reasoning can be applied to the transverse plane, where crossbite problems are represented. These transverse deviations may interact with either or both the sagittal and vertical deviations.

The Ackerman-Proffit system of classification can best be understood by its stepwise application, which is discussed later in the section on clinical evaluation.

Head Orientation. Although the importance of evaluating dentofacial traits in all three planes of space has been emphasized, the orientation of the head, teeth, and jaws was not specified. For many years, there was a quest to identify the most stable and reliable landmarks within the skull to use as reference points for cephalometric analysis. For over a century, anatomists and physical anthropologists used the Frankfort horizontal line for skull orientation. This dilemma has largely been resolved by using an external type of reference that does not relate to the skeleton—natural head position (NHP) as determined by the patient's visual axis. NHP is the most rational physiologic and anatomic orientation for evaluating the face, jaws, and teeth.[65–67] NHP is the orientation of the head determined by the visual axis and inner ear, and it has been demonstrated that each individual, while standing or walking, tends to orient his or her head in space so that it returns to a reproducible position when he or she looks at an object infinitely far away on the horizon. The same effect can be obtained by having the patient look into his or her own eyes using a mirror placed about 3 feet in front of the patient. Under these circumstances, the patient's visual axis is effectively parallel to the floor. It has also been shown that NHP is a highly repeatable position over time. The availability today of miniature three-dimensional sensors will soon

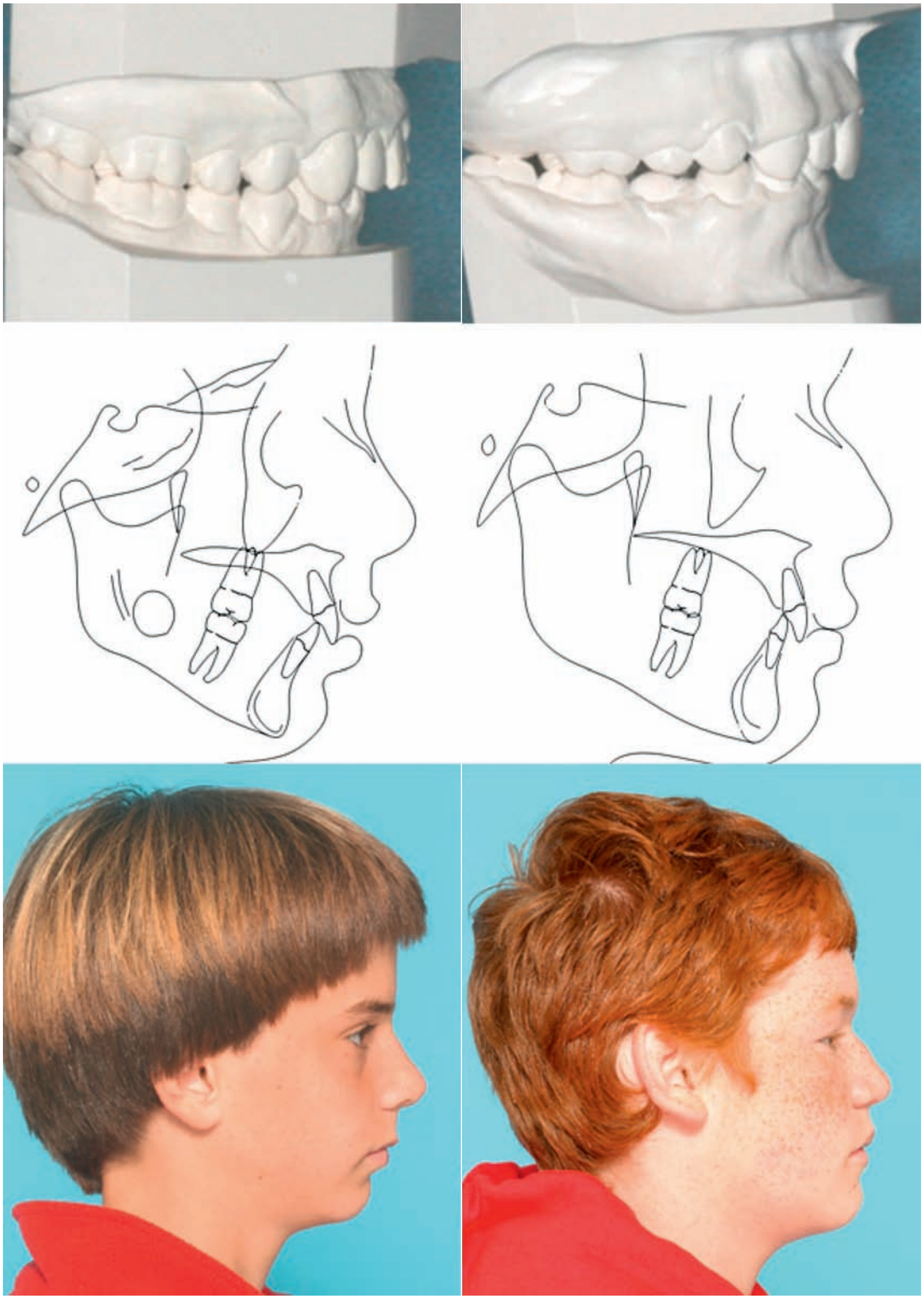
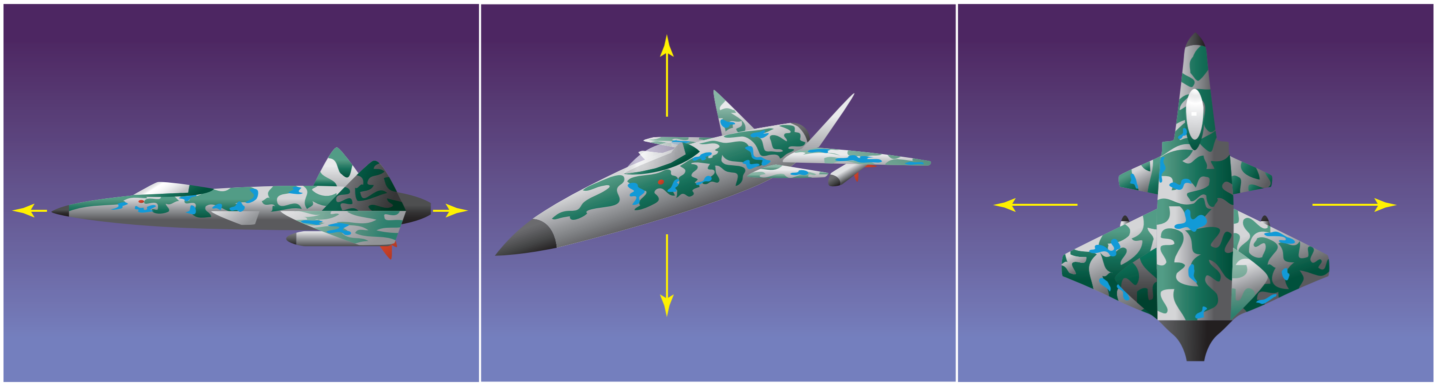
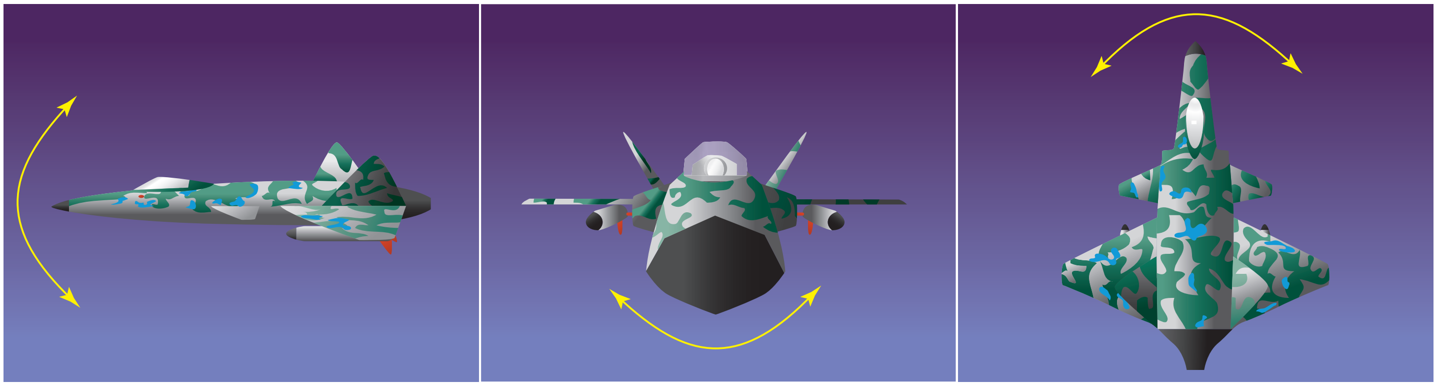


FIGURE 1-12 Shown are two patients of nearly the same age who have similar orthodontic conditions when only the characteristics of their dental occlusion are taken into consideration. Their underlying skeletal patterns and resultant dental compensations (e.g., mandibular incisor inclinations), as well as their soft-tissue facial profiles, are quite different. These two analogous patients require quite different treatment plans.

Six Degrees Of Freedom



Longitudinal (forward and backward thrust) Vertical (aircraft moves upward and downward) Lateral (aircraft moves from side to side)



Pitch (nose pitches up or down) Roll (wings roll up or down) Yaw (nose moves from side to side)

FIGURE 1-13 An airplane's ability to maneuver in space can be described as 6 degrees of freedom. An airplane's attitude, or orientation relative to the direction of travel, is analogous to the orientation of the dentition within the dentofacial complex. Pitch, roll, and yaw are descriptors that can be used for the esthetic line of the dentition. Pitch represents the occlusal plane in sagittal view, roll is analogous to the occlusal plane in frontal view, and yaw is a way of describing rotation of the dentition and jaws around a vertical axis. Yaw problems are manifested as midline deviations, facial asymmetries, or Angle subdivision molar relationships.

allow NHP to be recorded for each patient. Such an innovation would render the cephalostat obsolete.

At least part of the clinical examination should be done with the head in NHP, cephalograms should be taken in NHP, and the orientation of three-dimensional images should be corrected to NHP. Once NHP is established with a true vertical axis, the teeth and the jaws can be oriented to the rest of the craniofacial complex by using the occlusal plane as the other reference plane.

Complex versus Simpler Patients

In this chapter, the overall approach to diagnosis is recommended. Nevertheless, the fact that many patients seeking an orthodontic consultation have already made a self-diagnosis, namely that they simply want braces, has in certain ways changed the diagnostic ground rules. In this circumstance it is often difficult to elicit a chief concern, because there is none. These patients or parents assume that the appearance of practically any smile can be enhanced, which is the service they are seeking.

Thus, the orthodontic decision-making process today begins at the first visit with a kind of triage, whereby the initial decision is merely to decide whether the patient has a complex condition requiring extensive records and analysis or a simpler condition primarily related to enhancement of smile esthetics. After making this judgment, the two processes whereby the orthodontist establishes a treatment plan are merely the different variations of the problem-oriented treatment-planning method shown in Figure 1-8. The difference in the less complex case relates to the variety of diagnostic records required and the depth in which they must be assessed prior to making a treatment recommendation. In short, the major difference between the two diagnostic processes is the robustness of the database. If treatment is entirely elective, the required database will consist of fewer diagnostic records and it is unlikely the problem list will be lengthy or complicated.

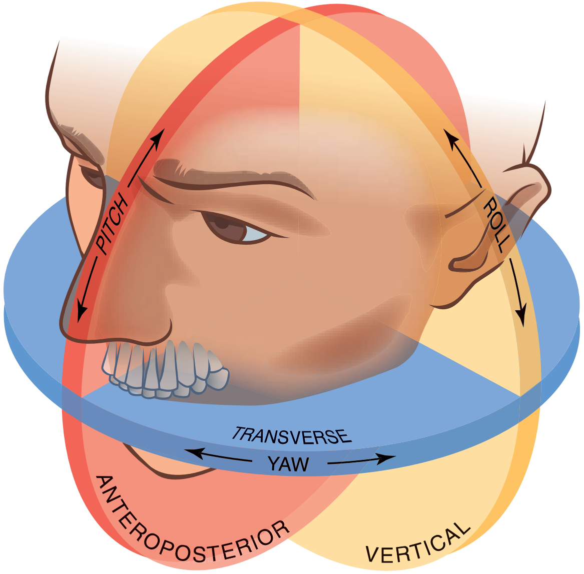


FIGURE 1-14 The face and dentition depicted with 6 degrees of freedom. The classic anatomic planes of the face are coronal, sagittal, and transverse. In the Ackerman-Proffit classification, the sagittal plane is referred to as anteroposterior, the coronal plane is designated vertical, and the transverse plane is the same as the occlusal plane and is used as a reference for the relative widths of the dental arches and any crossbite relationships that might exist. When the three discs representing the three planes of space are rotated, they demonstrate pitch, roll, and yaw of the occlusal plane. When the vertical disc rotates, it creates roll of the occlusal plane; when the sagittal disc rotates, it creates pitch of the occlusal plane; and when the transverse plane rotates, it simulates yaw.

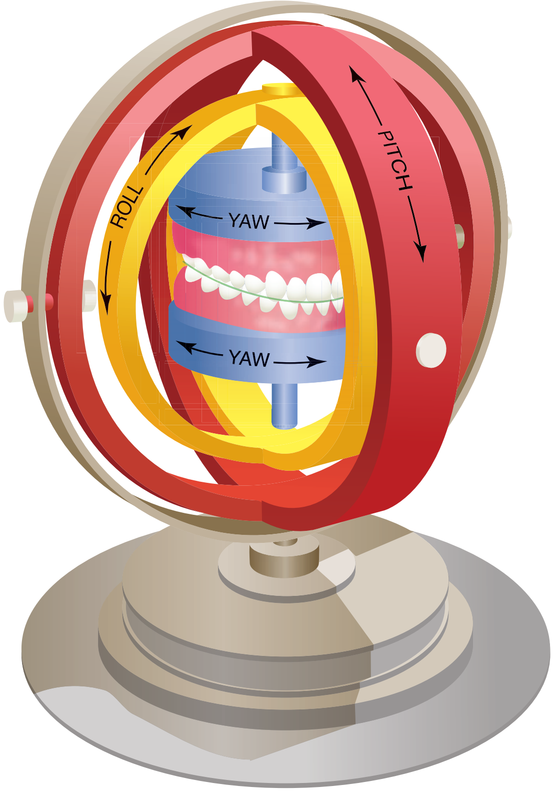


FIGURE 1-15 A gyroscope can demonstrate how the dentition's rotational orientation interacts as pitch, roll, and yaw. During a clinical examination, it is important to visualize the orientation of the esthetic line of the dentition (in this illustration, it is the *green line* at the facial incisal edges of the teeth). This model makes it clear how the anteroposterior, transverse, vertical, pitch, roll, and yaw are highly dependent on one another.

Orthodontic Database

Case-Specific versus Comprehensive Database. As has already been stated, the key to the effective use of the problem-oriented approach to orthodontic treatment planning is to establish an appropriate database prior to generating a problem list. We now use the term "case-specific" database in place of the prior term "comprehensive" database, because when an orthodontic condition merely requires enhancement, such as the ironing out of a few wrinkles in a smile, it is certainly not necessary to have a CBCT scan, as an example, as part of the database. On the other hand, if an impacted canine is identified from viewing a panoramic radiograph, the highest standard of care today is to obtain three-dimensional imaging before making any final treatment-planning decisions (Figure 1-17, *A* and *B*). The question in this case is whether the canine can be surgically exposed and its eruption orthodontically assisted or whether some other plan might make more sense. The alternatives in this case are to either extract the canine and try to preserve the central incisor for as long as possible or extract the central incisor with the compromised root and bring the unerupted canine into the central incisor position. Neither option is an ideal solution, and this problem serves as an example of where compromise and patient/parent input are essential.

It has been shown that orthodontists are able to base their treatment-planning decisions primarily on information derived from study models or photographs with only a modest change in plan with each additional diagnostic record.[68,69] Thus, the database should be assembled in such a way that it can begin to be synthesized from the start. Yet, the second key to effective treatment planning is to thoroughly review the data contained in the database. The rationale for being careful in constructing the database is to make sure some feature of the orthodontic condition is not being overlooked prior to compiling the problem list. There is a minimum standard for necessary orthodontic records, but there is no longer the requirement of a full battery of diagnostic records for every patient. For instance, an orthodontist may choose to acquire a supplemental posteroanterior cephalometric radiograph for an individual with asymmetry (or, perhaps even better, would consider that individual a candidate for CBCT), but it is superfluous to obtain a frontal radiographic image for every candidate for treatment. The minimum standard for orthodontic records is facial and intraoral photographs and a panoramic radiograph and a lateral cephalogram for patients in whom changes in the jaw relationship and/or relationship of the teeth to

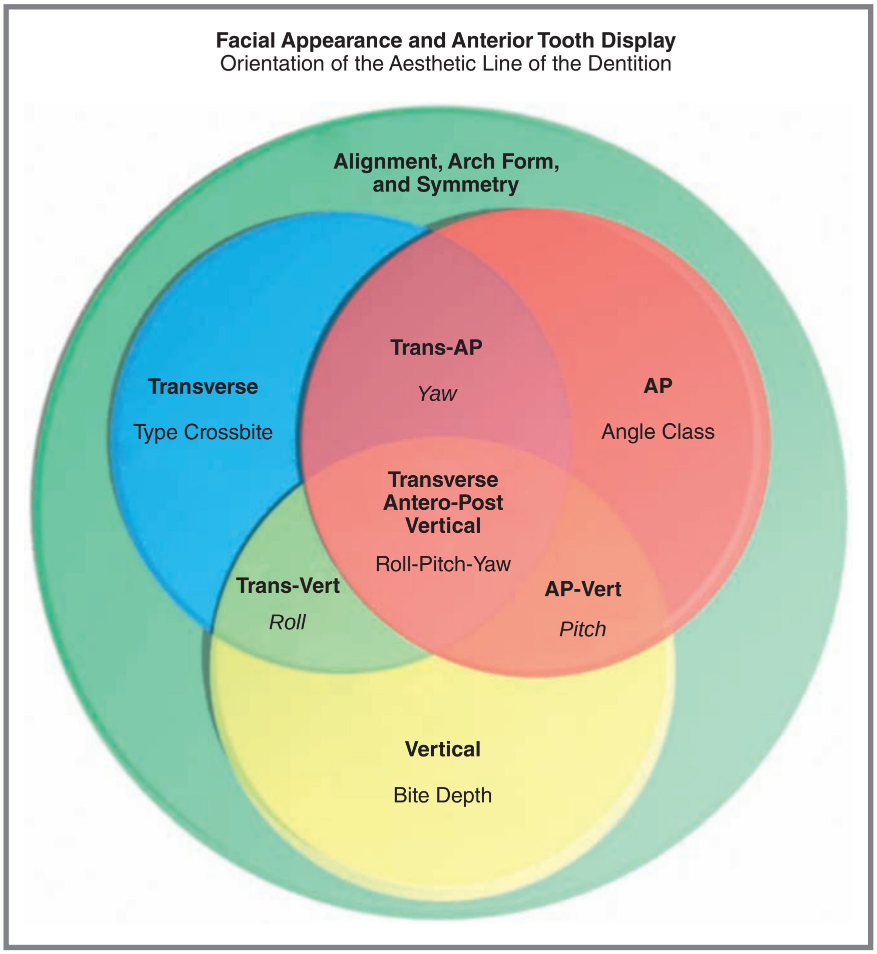

Facial Appearance and Anterior Tooth Display
Orientation of the Aesthetic Line of the Dentition
Alignment, Arch Form, and Symmetry
Transverse
Type Crossbite
Trans-AP
Yaw
AP
Angle Class
Transverse Antero-Post Vertical
Roll-Pitch-Yaw
Trans-Vert
Roll
AP-Vert
Pitch
Vertical
Bite Depth

FIGURE 1-16 Ackerman-Proffit orthogonal analysis. When the disks representing the three planes of space shown in Figure 1-14 are stacked as a Venn diagram, it shows the interactions between the anteroposterior, transverse, and vertical dimensions. The three overlapping disks are shown atop a disk representing dental arch alignment, symmetry, and arch form, and all four disks are shown on a box representing the framework of facial appearance, anterior tooth display, and orientation of the esthetic line of the dentition. With this classification, five or fewer characteristics can fully describe the dentofacial traits of any orthodontic condition.

the jaws is likely to occur during treatment. The timing of when a specific minimum standard diagnostic record is taken depends on the complexity of the problem. For instance, in the one-step diagnostic and treatment-planning method (Figure 1-18), the cephalogram is usually taken after the preliminary treatment plan has been outlined. The lateral head film is used later when the detailed plan is generated.

By working from a comprehensive database, orthodontic diagnosis becomes the process of systematically synthesizing the manifold factors involved in a complex situation into a discrete list of problems, each of which suggests a tentative solution. Proper diagnosis in clinical orthodontics is equivalent to a good hypothesis in basic research. A well-stated hypothesis is a question so well phrased that an answer is inherent in the question. A well-conceived diagnosis automatically suggests alternative treatment plans. This analogy can be taken one step further. Orthodontic treatment is to diagnosis what the experiment is to a research hypothesis. The results tend to support or reject one's diagnosis or hypothesis.

Data Collection at the First Contact. Data collection and development of the diagnostic database begin with the very first encounter with the patient or parent. This first contact is almost always by telephone, and important demographic information including the e-mail address should be obtained at this time. The patient's age, the source of the referral, the family dentist, and other patients and families that the prospective patient knows are all clues regarding what the patient and family may already know of an orthodontist's practice. Obviously, if the call is to set up an appointment for the sibling of a patient already in the practice, there is usually instant rapport. If the prospective new patient is another patient's best friend in school, it is likely that she or her already has great awareness of the practice. Today, the majority of patients' parents have had orthodontics themselves, and it is generally easy to quickly integrate them into one's practice routine.

Just as it would be an error in taking for granted that the parent is an old hand at orthodontics, there is an equal danger of having the caller feel the receptionist is talking down to them. The ease or difficulty with which the receptionist can schedule the first appointment may indicate the type of demands this family may make and the cooperation that might be received in the future. All information should be entered directly into the office's computer system, including discreet notes regarding the receptionist's first impressions. There should be a window opened on the computer screen that will serve

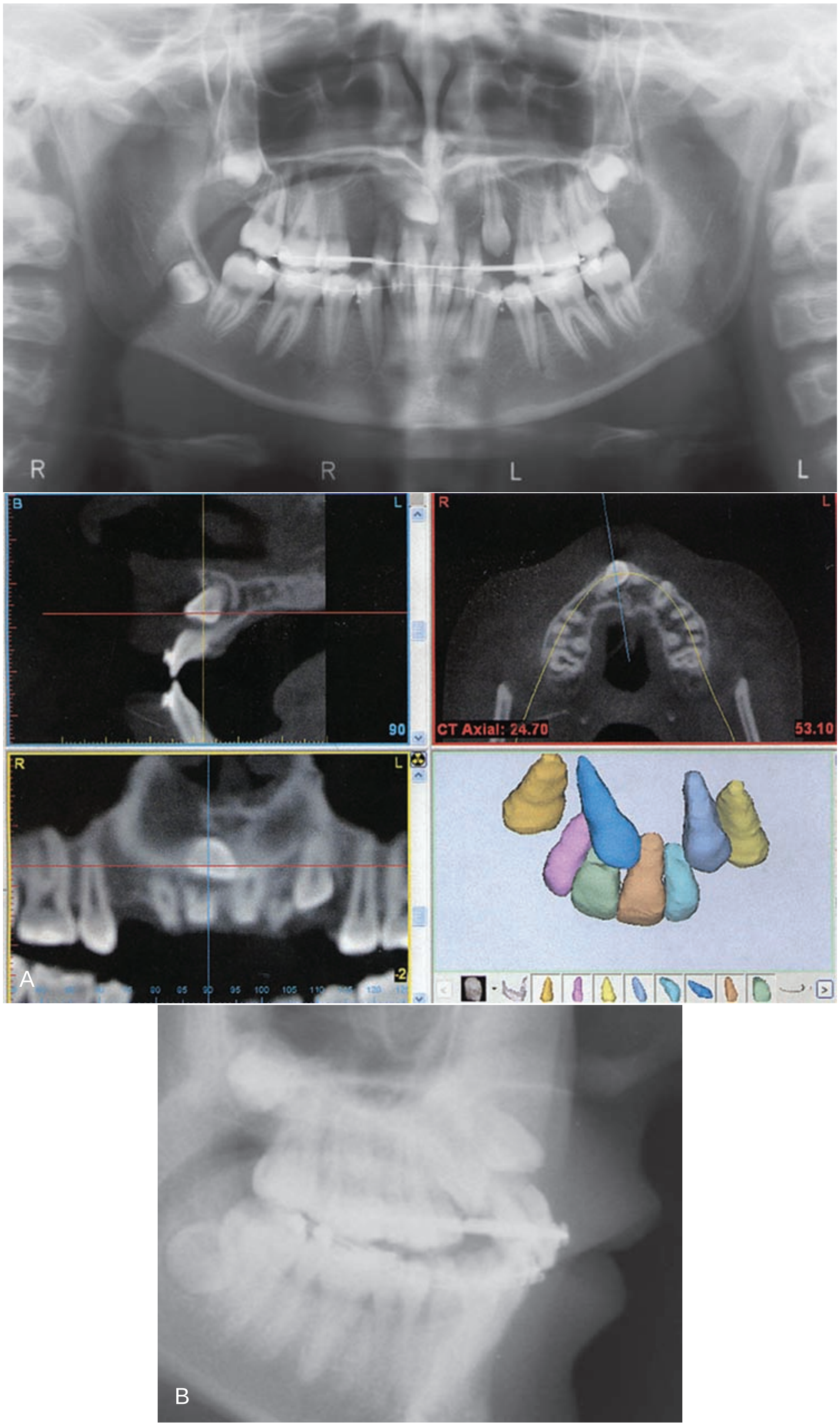


FIGURE 1-17 **A, B,** Three-dimensional radiographic imaging with cone beam computed tomography can be a valuable adjunct to panoramic radiography and periapical localizing films in assessing impacted canines. For this patient, although the position of the impacted canine and the significant resorption of the root of the central incisor can be seen clearly from the panoramic image and from the lateral cephalogram, there are many cases where the additional imaging is very useful in making a prudent decision about which tooth to extract (the impacted canine or the compromised central incisor) in a difficult situation like this one.

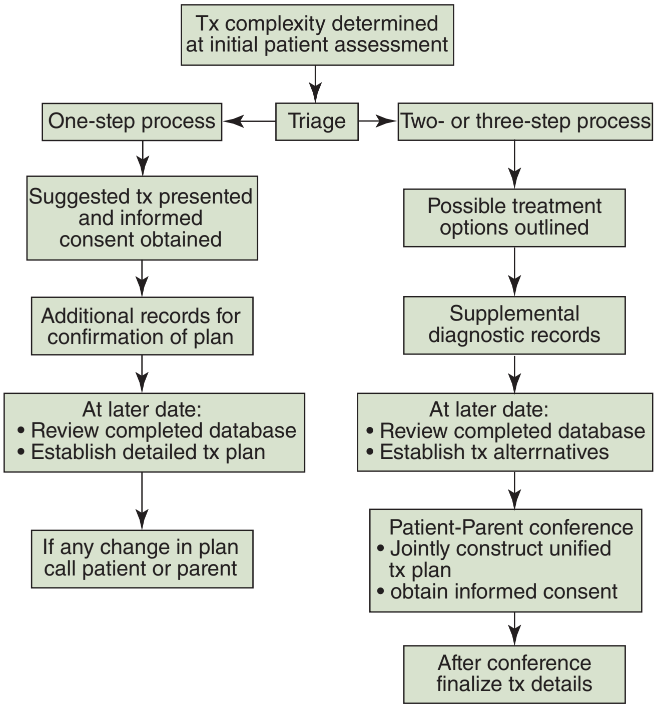

Tx complexity determined at initial patient assessment
Triage
One-step process
Two- or three-step process
Suggested tx presented and informed consent obtained
Additional records for confirmation of plan
At later date:
• Review completed database
• Establish detailed tx plan
If any change in plan call patient or parent
Possible treatment options outlined
Supplemental diagnostic records
At later date:
• Review completed database
• Establish tx alterrnatives
Patient-Parent conference
• Jointly construct unified tx plan
• obtain informed consent
After conference finalize tx details

FIGURE 1-18 This flow sheet shows the decision tree regarding the selection of a one-step or a two-step or more treatment-planning process. A critical decision is made at the time of the initial clinical evaluation regarding the complexity of the orthodontic condition. We call this process triage. The degree of complexity of the orthodontic condition will determine the required robustness of the database and what additional steps will be necessary before the orthodontist will be able to jointly construct a treatment plan with much needed input from the patient and/or parent.

as a checklist to guide the receptionist in systematically collecting these data. Usually, the receptionist will be able to glean the motivation for treatment during the first call. This is the first step in building an orthodontic database.

At the end of the initial telephone call regarding scheduling a patient evaluation, the caller should be informed that if they would be kind enough to fill out a patient questionnaire and have it ready at the first visit, it will greatly facilitate the initial appointment. The caller should have the option of downloading the questionnaire from the office website, having it e-mailed to them as an attachment, or having it mailed to them as a hard copy.

Patient/Parent Interview: Medical-Dental History

A well-designed patient information questionnaire allows the patient or parent to provide the medical and dental health history so that all positive findings prominently stand out. Then a simple glance at the questionnaire alerts the clinician to the questions that require follow-up. There are a few major questions that always must be asked. The first, of course, is when the patient last saw his or her physician. If it was within the last year and was for a regular checkup, this usually is a good sign.

Another important question is whether the patient has ever been hospitalized and, if so, for what reason. For prospective orthodontic patients, one usually includes a specific question as to whether the patient has had a tonsillectomy and/or an adenoidectomy. This may be a clue that the patient had an earlier airway problem, which might have affected the jaw and tongue posture. Sometimes the admission to the hospital was the result of trauma, and it is important to know whether the jaws, face, or teeth were involved in the accident. If they were, the orthodontist should be particularly vigilant regarding facial asymmetry that may have resulted from a healed subcondylar fracture. A closer look at the panoramic radiograph would be indicated if this is a suspicion. If the injury involved one or more teeth, a closer evaluation of the vitality of the teeth involved is clearly indicated, and the patient or parent should be made aware that orthodontic tooth movement can possibly exacerbate periapical symptoms.

It is best for the mutual confidence of the parent, patient, dentist, and orthodontist to make these dental health determinations before treatment begins. If told beforehand, the parent or patient views it as an explanation. If explained after the fact, they see it as an excuse! Because parents often do not realize the relationship between overall health, dental health, and dentofacial development, persistence in pursuing these questions is important.

The next issue that must be considered is whether the patient is taking any medications. Occasionally a parent is reluctant to inform the orthodontist in front of the child that they have seizures (epilepsy) but the parent will indicate that phenytoin (Dilantin) or some other anticonvulsant drug is being taken. This will not only influence the management of the child in regard to medical emergencies but also influence tooth movement if there is gingival hyperplasia. If a patient is taking medication typically prescribed for attention-deficit disorder, the issue of potential compliance with treatment should be explored further. If a patient has recently been prescribed isotretinoin (Accutane) for severe cystic acne, the orthodontist and patient should be aware that severe lip dryness with cracking is a common side effect of this medication and that becoming pregnant while taking Accutane is associated with high risk of birth defects.[70] In adults being treated for arthritis or osteoporosis, high doses of prostaglandin inhibitors or resorption-inhibiting agents may impede orthodontic tooth movement. These examples should serve as a reminder that an orthodontist must know the contraindications of orthodontic treatment and be able to rule out that any of these factors are involved with any given patient.

Meeting the Patient and Eliciting the Chief Concern

Before the orthodontist meets the patient at the first appointment, the demographic and historical information should be reviewed, and photographs and a panoramic radiograph should be available. The advent of digital photography and radiography has markedly improved the ease and efficiency of obtaining these records. The treatment coordinator, immediately prior to the orthodontist meeting the patient, usually takes photographs and a panoramic radiograph. After briefly reviewing these records and rallying his or her thoughts, the orthodontist is ready to meet the patient.

Some practitioners prefer to have the parent present when he or she meets the patient; some find it advantageous to examine a child patient independently first and then invite the parent to the treatment area to receive the report. It is sometimes far easier to establish rapport with the patient if there is no parent present. Some parents insist on answering questions addressed to their child by the orthodontist and enjoy talking to the orthodontist as the initial evaluation is being conducted, which can be distracting. On the other hand, there are "helicopter" parents who insist on hovering over their children in every situation, and they should be given the choice of being present if they wish. It is poor form for a staff member or orthodontist to say that the parent's presence or absence is an "office policy," because most people resent rigid adherence to some arbitrary rule.

At the first meeting, the orthodontist should not assume that appearance is the patient's major concern just because the teeth appear unattractive. Nor should the dentist focus on the functional implications of, for instance, a crossbite with a lateral shift without appreciating the patient's concern about what seems to be a trivial space between the maxillary central incisors. As we have noted, for an individual with what appears to be reasonably normal function and appearance and appropriate psychosocial adaptation, the major reason for treatment may well be a desire to improve appearance "beyond normal." The greater orientation of modern family practice toward cosmetic dentistry increases the chance that a patient may be referred to an orthodontist for comprehensive treatment to improve dental and facial appearance.

From the outset, the orthodontist must determine whether the prospective patient is a suitable candidate for treatment, because there are notable exceptions to the validity of self-determination of the need for orthodontic intervention. An example of such an exception is an adult patient with body dysmorphic disorder (BDD), which is a condition marked by excessive preoccupation with an imaginary or minor defect in a facial feature or localized part of the body[71]. These individuals almost always have unreasonable expectations as to how a change in one or more of their dentofacial features will alter their sense of social well-being and quality of life. They can be very persuasive, and they often goad health professionals into performing treatments against their better judgment. If BDD is suspected, the patient and the orthodontist are both well served by seeking a consultation with a mental health professional. Potential adult patients who might have a mild form of BDD may be more prevalent than currently suspected. The orthodontist also must be wary of parents (the "pageant mom") who push for early treatment with questionable benefit or adolescents who have unrealistic expectations about what orthodontic treatment might accomplish for them.

Perhaps the easiest and most direct way to find out how the patient feels about orthodontic treatment is to ask the simple question, "Do you think you will need braces"? Most children today think that braces are inevitable and thus usually answer affirmatively. Occasionally, the reaction is a shrug of the shoulders. Only rarely will a child say that although his (or her) parents think he should have braces, he does not want them. For the patient who responds with a shrug, the important follow-up question is, "If your parents and I think you will be helped by braces, will you go along with the recommendation?" For children or adolescents who do not appear to be motivated to have treatment, it is rare that they will exercise good oral hygiene or elastic wear during treatment. From almost anyone's perspective, it is much more acceptable to have treatment that is done *for* you than to have treatment that is done *to* you. In this circumstance, there is merit in telling the parent that postponing treatment until the patient is either more mature or simply more motivated may be the best alternative.

For the individual who is convinced he or she will require orthodontics, an important question is whether any one feature is of greater concern than another. It is important to know this for two reasons. First, one of the most embarrassing mistakes an orthodontist can make is failing to address an issue that is of major concern to the patient. The orthodontist may or may not agree with the patient's assessment—that judgment comes later. At this stage the objective is to find out what is important to the patient. Second, to allow for the most effective treatment planning, it is important to take into consideration what dentofacial trait or traits are most important to the patient or parent when prioritizing the problem list.

Clinical Evaluation

Although the sequence of steps in completing the database can vary even within a single practice, depending on the complexity of the case (see later), a comprehensive clinical examination usually follows immediately after review of the information just discussed. The orthodontist should make some diagnostic determinations "from the doorway" regarding the patient's face, posture, and expression. One can often tell from the first moment whether the orthodontic problem will be largely a dental one or a difficult skeletal or facial problem.

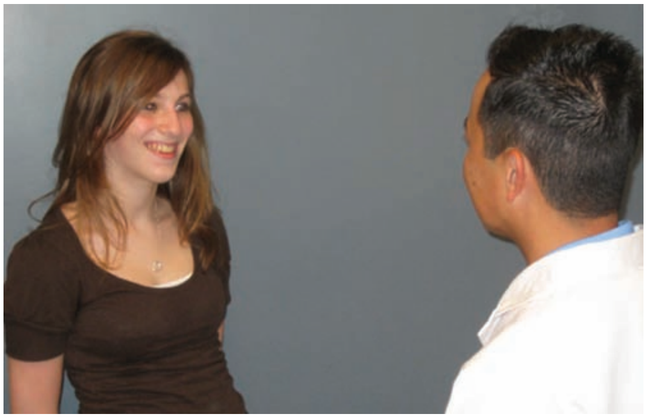


FIGURE 1-19 An essential element in performing the initial clinical examination is the assessment of facial form, anterior tooth display, and orientation of the aesthetic line of the dentition. At some point during the initial patient examination, the patient should either stand and look at the horizon or be seated comfortably in a standard chair with back supported and asked to look at his or her image in a mirror, at a distance of approximately 3 feet (i.e., natural head position [NHP]). The orthodontist is seated at the same eye level on a wheeled chair or stool enabling an assessment to be made in front and profile views. The orientation of the subject's head during this assessment can markedly alter the orthodontist's perspective.

Facial Examination. The evaluation of facial appearance should be done with the patient's head in NHP (i.e., standing or sitting up), not with the patient prone in a dental chair[71] (Figure 1-19). The frontal view should be assessed first in repose and then with the lips sealed to determine if the patient manifests lip incompetence. The patient is then observed during facial animation while speaking and smiling. After all, it is ultimately anterior tooth display (the smile zone) over which the orthodontist has the greatest control.[72]

In assessing the face in its broadest context, one tries to rule out any genetic defects or partial expression of genetic defects. The distance separating the eyes can often give a clue to this kind of problem. In a number of genetic defects affecting the face and teeth, one frequently finds hypertelorism (eyes that are too far apart). Malformations of the ears may be associated with one of the brachial arch syndromes, which can affect the mandibular condyle. For a more complete account of this subject, see Gorlin et al.[73]

Although orthodontists in private practice rarely treat patients with malformations other than cleft lip and/or palate, it is important to consider the possibility of other syndromes. A patient with severe mandibular retrognathia at age 15 years, for instance, may have had a Pierre Robin sequence and earlier in development may have had a more pronounced problem. Frequently, knowledge of this type does not markedly affect the treatment plan, but it does often temper the treatment goals based on therapeutic modifiability. Sometimes a surgical approach to treatment will be selected, based on the recognition that one is dealing with the result of a pathologic process rather than normal anatomic variation.

After having assessed the overall head and face, the orthodontist then focuses on the lower face, which is most easily affected by tooth position. Lip prominence is usually described as convex, straight, or concave, and this judgment is made relative to the nose and chin. A large nose and well-developed chin can easily mask a protrusive dentition. Similarly, the opposite situation of a small nose and weak chin can make a child appear more facially convex. Examining the parents and older siblings may give some hint regarding final dimensions of these structures.

The facial photographs and lateral cephalogram are helpful in assessing certain aspects of facial appearance, but some features must be examined chairside. Assessment of the dental midline as it relates to the midline of the face and the symmetry of the face are examples. Lip competence is another. Can the patient or does the patient keep his lips approximated when at rest, and is this done with ease or strain? Does the patient, when in repose or smiling, have a high upper lip line showing a wide band of gingiva? Chapped lips and inflamed gingiva in the maxillary anterior region are often indications of a patient who is a mouth breather or whose oral seal is inadequate because of extremely protrusive teeth.

Intraoral Examination: Health of Hard and Soft Tissues. Once the visual and tactile examination of the face is complete, an evaluation should be made of the intraoral hard and soft tissues. This should immediately reveal the general oral health of the patient. Just as the orthodontist should view the overall health of the child broadly, he or she should also look at oral health from the broadest possible perspective. What has been the caries incidence? How faithful has the child been with home care, and, generally speaking, what is the oral health picture?

Some orthodontists begin plaque control programs for children before initiating orthodontic treatment. In university clinics, patients are usually not accepted for treatment until they can demonstrate adequate home care. The experienced orthodontist knows that this is as fundamental to success in orthodontics as the appliance that is used. Poor gingival health adversely affects tooth movement and may progress to a more significant periodontal problem. Most periodontal sequelae of orthodontic treatment are self-correcting once the orthodontic appliances are removed, but enamel decalcification resulting from poor hygiene can mar an otherwise beautiful orthodontic result. It has been suspected that systemic disorders such as allergies may be associated with root resorption. When this hypothesis was tested, no statistically significant correlations were found.[74] It is believed that prolonged treatment can increase the risk of root resorption, devitalization, and obliteration of the pulp chambers, although at the present time there is little known about the undoubted molecular genetic basis underlying these processes. The hazards of orthodontic treatment may be minimized with careful diagnosis and treatment planning.

As part of visual and tactile examination of the dentition, it is important to count the teeth. A quick check should be made for mobility of primary or permanent teeth. In the mixed dentition, one should palpate for the maxillary unerupted canines, since often it is not possible from the radiographs to ascertain whether these teeth are erupting labially or palatally. It should be possible to palpate these teeth labially. Ankylosed primary teeth usually appear submerged. Tapping these teeth with the handle of a dental instrument usually produces a somewhat higher "ring" than a normal tooth. Any other abnormalities of the hard tissues should be noted, such as enamel defects and internal or external root resorption.

There is little unique about the examination of the intraoral soft tissues for a prospective orthodontic patient. This evaluation begins with checking the buccal and labial mucosa, the tongue, and sublingual areas for possible abnormalities. Significant oral pathology in children is a very rare finding. However, the orthodontist should take particular note of unusual frenum attachments. Two points should be noted:

1. Is there a heavy frenum attachment in the area of a maxillary midline diastema? The diastema may or may not be caused by the frenum in such cases. Whether surgical removal is indicated was discussed by Bergström, Jensen, and Mårtensson.[75] They found that in the short term, a frenectomy in the absence of orthodontic treatment allowed the maxillary midline diastema to close more quickly; however, within 10 years those patients who had no surgery compared favorably with those individuals who had the frenectomy in regard to the size of the diastema.
2. Is there gingival clefting or recession in the lower incisor region near a high frenum attachment? Such an attachment often causes periodontal problems.

Gingivitis is relatively common in children; it is generally plaque related due to poor oral hygiene and can be exacerbated by faulty tooth alignment such as a high labially positioned maxillary canine. Severe periodontal problems, however, are uncommon in children even in the presence of severe malocclusion, and the discovery of bone loss should lead to suspicion of underlying systemic illness such as diabetes, hormonal imbalances, or blood dyscrasias. Occasionally, aggressive juvenile periodontitis (rapid bone loss around central incisors and first molars for no apparent cause) is observed in children referred for orthodontic treatment.[76] The prognosis for involved teeth in this situation is poor, but orthodontic treatment may still be indicated to prepare the patient for ultimate prosthetic replacement of these teeth.

Two other periodontal problems often are observed in patients who are candidates for orthodontic treatment. These are clefts of the gingiva around severely protrusive or badly rotated mandibular incisors, and gingival hyperplasia and fibrosis in children on seizure medication such as Dilantin. Patients who have gingival clefts and poor oral physiotherapy will frequently require periodontal surgery to provide a wider zone of attached gingiva, while those on Dilantin or equivalent drugs may require gingivectomy or gingivoplasty while under orthodontic treatment. Both types of periodontal surgery can be performed while orthodontic appliances are in place, but early consultation with the family dentist or periodontist is necessary before proceeding with an orthodontic treatment plan. New surgical techniques with lasers can deal effectively with removing excess gingiva such as an operculum distal to a permanent second molar or performing a soft tissue uncovering of an unerupted tooth.[77] The topic of lasers in orthodontics is presented in Chapter 30.

In adult patients, a periodontal probe should be used during the gingival evaluation. Bleeding on gentle probing is an indication of a periodontal condition that can simply be marginal gingivitis, on the one hand, or more serious periodontal disease with loss of attachment and alveolar bone loss at the other extreme. The basic principle is that orthodontic tooth movement in the absence of inflammation is similar to the physiologic response related to tooth migration or drift. If the same tooth movement is attempted in the presence of inflammation, the process becomes pathologic and more like periodontal breakdown and disease. Therefore, in adult patients, it is necessary for either the general dentist or a periodontist to perform initial periodontal preparation before orthodontics to eliminate any inflammation.

Soft Tissue Function. The size of the tongue is often hard to assess, but some attempt should be made to evaluate its general dimensions at rest and when protruded. It is important to ask the patient to raise his tongue to the roof of his mouth with the mouth open. Inability to do this suggests ankyloglossia, and the patient may benefit from surgery to allow better tongue movement.

Speech evaluation properly belongs in the hands of trained speech specialists, but sometimes parents seek orthodontic treatment as a way to help their child with speech problems, and an orthodontist should be able to discuss errors in speech that could be related to malocclusion versus those that are not. Correcting the orthodontic condition is unlikely to remedy even the related speech errors without associated speech therapy. Orthodontic treatment will, of course, have no effect on other common speech errors of children, such as substituting one sound for another.

Jaw Function. An important part of the clinical examination is to establish the path of closure of the mandible and to determine if the maximum intercuspal position (centric occlusion) corresponds with the retruded contact position (centric relation). If these positions do not correspond, one should note the premature contacts and any convenience shifts that might exist. If there is a large discrepancy, the occlusion should be classified in retruded contact position, whereas if the discrepancy is small, it is easier to use the intercuspal position. If this important information is not considered as the problem list is developed, it is quite possible that the treatment plan will be poorly conceived.

The patterns of wear on the cusps and incisal edges of teeth often indicate the parafunctional movements of the jaws. Grinding or clenching of the teeth can affect orthodontic treatment, particularly in regard to the vertical dimension.

During the clinical examination, the TMJs should be palpated and any crepitus or pain in the joints should be noted. Even when severe occlusal disharmonies are present, children presenting for orthodontic treatment rarely have TMD problems. The orthodontist is more likely to encounter these problems during or after treatment in older adolescents or in adults whose tolerance of muscular imbalances is reduced. The tolerance of children for occlusal disharmonies does not mean that these are unimportant in orthodontic diagnosis. It is particularly important that occlusal shifts and slides are detected and corrected during the orthodontic treatment. For a complete evaluation of TMJ function, the reader should refer to texts on this subject.[78]

Use of Radiographs during the Clinical Examination. Panoramic radiography with automatic film processing or, more recently, digital images has changed the oral examination and initial evaluation for most orthodontists. Orthodontists with access to this kind of technology usually will not perform the initial oral examination without first viewing a panoramic radiograph. Teeth that are present yet unerupted, impacted teeth, supernumerary teeth, and any congenitally missing teeth can be ascertained from the outset. The panoramic film will also reveal any periapical pathology or periodontal breakdown.

If treated or untreated caries is noted during the oral examination, bitewing radiographs should be obtained. It is likely these additional radiographs are available from the referring dentist, but the orthodontist needs to be sure that these radiographs exist and that active caries is being treated. With each succeeding year, the guidelines for the use of radiographs in dental practice become stricter and there is little indication that practitioners are becoming more compliant with the guidelines.[79] It is extremely important that the orthodontist keep up to date with the guidelines to minimize the amount of radiation used for diagnostic purposes.

From the panoramic radiograph, one also should assess the amount of mineralization of the unerupted teeth and, using root mineralization norms, establish the dental age of the individual. The amount of root mineralization can also be used for predicting the timing of tooth emergence. For instance, if root initiation has just begun on a mandibular second premolar, it will be approximately 4 years until this tooth reaches gingival emergence. It is also a good idea to establish the dental age based on eruptive means, and for this purpose one can use one of several published standards. Because the orthodontist's task can never be considered complete until all of the second permanent molars are erupted and in proper occlusion and the third molars accounted for, the significance of the dental age in this regard should be obvious. For a patient whose dental age is lagging considerably behind the chronologic age, the orthodontist frequently would prefer to wait until the late stages of the transitional dentition before commencing comprehensive treatment with active mechanotherapy. If the skeletal age is advanced and there is a skeletal problem, however, it may be necessary to start treatment based more on the pubertal growth spurt than on the dental age. Thus, it is important to consider the dental age, the skeletal age, and the emotional age of the individual relating to the readiness for orthodontic treatment. There is probably no more fundamental biologic principle underlying orthodontic diagnosis and treatment planning than this concept of biologic ages. A fundamentally correct treatment plan instituted at the wrong time can yield poor results. Thus, for certain kinds of problems, treatment timing is probably the most critical decision that the orthodontist has to make. For a further explanation of mixed dentition diagnosis and treatment planning, see Chapters 13 and 14.

Systematic Description of Dentofacial Traits in Clinical Evaluation. The Ackerman-Proffit Orthogonal Analysis (classification system) can most easily be described by outlining its method of application. The evaluation is carried out in five steps corresponding to each of the five characteristics, or descriptors, of malocclusion. In this classification, a patient with ideal occlusion accompanied by excellent facial balance and a balanced smile requires no descriptors at all to characterize the situation. A patient with a Class I malocclusion with crowding, but excellent balance of their face and smile and no crossbites and normal bite depth, requires only one descriptor to characterize the problem: alignment—maxillary and mandibular crowding. This is the reason only five or fewer major characteristics of any orthodontic condition are needed to fully portray the situation.

Step 1: Evaluation of Dentofacial Appearance. This includes assessing anterior tooth display, as well as the relative convexity and concavity and divergence of the face in profile view and vertical proportions of the face. As discussed previously, faces can be categorized in profile view by their relative convexity and divergence (Figure 1-20). In anterior view, the vertical characteristics of the face can be expressed by the proportion of facial width and height. In doing so, patients present along a spectrum from short and wide (brachyfacial) to long and narrow (dolichofacial). Average facial proportions are more or less of ovoid shape, and these faces are called mesofacial. Dolichofacial individuals

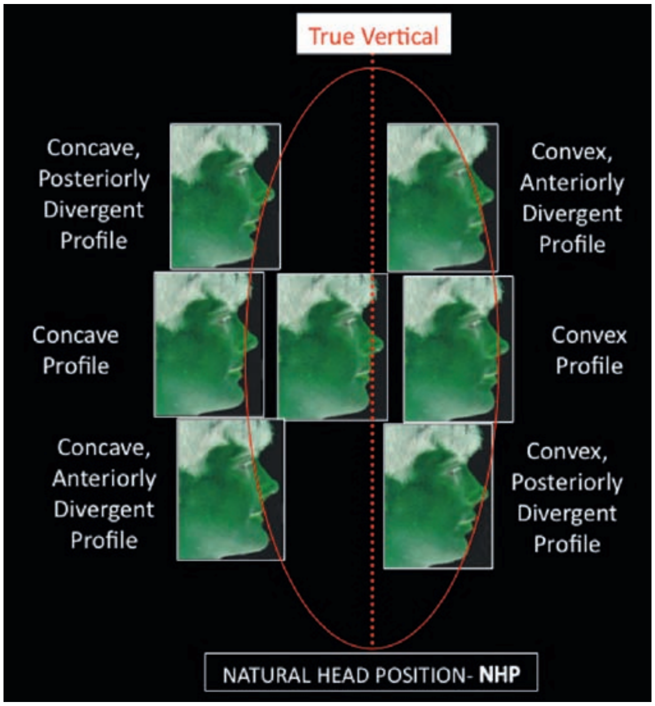

True Vertical
Concave, Posteriorly Divergent Profile
Convex, Anteriorly Divergent Profile
Concave Profile
Convex Profile
Concave, Anteriorly Divergent Profile
Convex, Posteriorly Divergent Profile
NATURAL HEAD POSITION- NHP

FIGURE 1-20 This illustration demonstrates that any facial pattern can be adequately described using the relative convexity or concavity of the facial profile and the relative anterior divergence or posterior divergence of the chin in relationship to the mid-face and upper face. Adding a description of face height, as well, nicely completes the picture (see Figure 1-21).

often have anterior open bite dental and skeletal relationships, and brachfacial individuals often have dental and/skeletal anterior deep bite relationships. In most instances, the clinician simply classifies faces from a vertical standpoint as short, average, or long (Figure 1-21). In terms of anterior tooth display, a smile is characterized by how well the teeth and gingival fit within the smile zone, which is defined by the lips. The lateral and sagittal cants of the occlusal plane and esthetic line of occlusion, as well as the rotation of the maxillae and mandible around a true vertical axis, are described using the terms "pitch," "roll," and "yaw." These features can be assessed when evaluating anterior tooth display. A more detailed analysis of facial form and appearance is presented in *Esthetic Orthodontics and Orthognathic Surgery*[19] and in Chapter 2 of this volume.

Step 2: Analysis of the Alignment and Intra-arch Symmetry. *Alignment* is the key word in this group; among the possibilities are ideal, crowded (arch length deficiency), spaced, and mutilated. It is obviously important to count the teeth in order to ascertain which teeth are present or absent. Irregularities of individual teeth are described if desired by the method of Lischer—namely, the suffix *-version* is used to describe the direction of individual tooth malalignments. For example, if a tooth is lingually displaced, it is said to be in linguoversion. If rotated, the tooth is said to be in torsiversion. Tooth

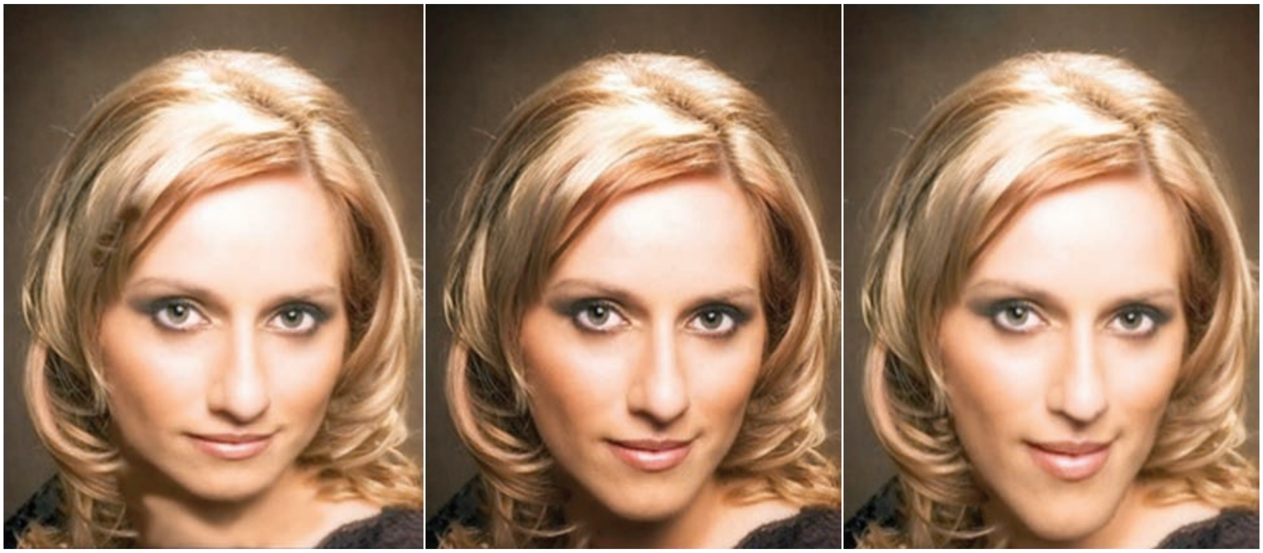

Short face Average face Long face

FIGURE 1-21 Classically, the ratio of face width to face height defines three basic types of faces. Today, the important observation rests with recognizing either an increased or decreased lower face height. This illustration shows computer-altered lower face heights ranging from short lower anterior face height to long lower face height. Long, narrow faces with increased lower face height usually have a tendency toward anterior open bite. Lower anterior face height is a reflection of the underlying skeletal pattern. Individuals with short lower face heights usually have relatively parallel horizontal facial planes (i.e., palatal plane, occlusal plane, and mandibular plane) and anterior deepbite. Patients with long lower face heights have horizontal facial planes that tend to converge posteriorly (see Figure 1-24). Of course, there are many exceptions to these rules.

malposition is described using 6 degrees of freedom. If a tooth is tipped mesially, it is in mesioaxiversion, and if the same tooth were not fully erupted, its position would be described as mesioaxi-infraversion.

If the dental midlines (maxillary dental midline and mandibular dental midline) do not correspond, the fault should be determined by looking at the midline of the face to decide whether the maxillary or mandibular midline or both are at fault and whether the deviation is the result of an intra-arch alignment issue or whether it is a yaw problem in which either the maxilla or mandible has rotated slightly around an imaginary vertical axis.

Step 3: Lateral Dimensions (Transverse Plane of Space). The faciolingual relationships of the posterior teeth are noted. The term "type" is used to describe various kinds of crossbite. A judgment is also made as to whether the deviation from ideal proportions and occlusion is basically dentoalveolar, skeletal, or a combination of the two. There is, of course, a continuous range from problems that are entirely skeletal to those that are entirely dental. Most patients have components of both, with one or the other predominating. If a transverse discrepancy is detected or suspected, it is important to measure the disparity. Measuring the mesiopalatal cusps of either the maxillary permanent first molars or second molars, or both, and comparing these measurements to the width of the central fossae of the mandibular first and second molars will accomplish this. Dental compensation for an underlying skeletal problem such as a constricted maxillae and narrow palatal vault is common in the transverse dimension. It is not unusual for the maxillary posterior teeth to be tipped facially to compensate for a transverse skeletal size discrepancy between the maxillae and mandible. If a bilateral palatal crossbite were the result of constriction in maxillary development, it would be called a skeletal problem. Similarly, constriction of the maxillary dental arch alone would be designated a dentoalveolar problem. As a general rule, maxillary or mandibular is used to indicate where the problem is located. "Maxillary palatal crossbite" implies a narrow maxillary arch, while "mandibular buccal crossbite," describing the same dental relationship, indicates excess mandibular width as the cause. The lateral cant of the occlusal plane (roll) is evaluated in relationship to both the intercommissure line and the interpupillary line (Figure 1-22).

Step 4: Anteroposterior Dimensions (Sagittal Plane of Space). In this dimension, the Angle classification is used and is merely supplemented by stating whether a deviation is skeletal, dentoalveolar, or both. The skeletal possibilities are normal, maxillary prognathism, mandibular retrognathism, maxillary hypoplasia, mandibular prognathism, or any combination of these. The sagittal cant of the occlusal plane (pitch) is also evaluated. Patients with severe Class II orthodontic conditions often have steeper occlusal planes accompanied by longer faces. The opposite is true of patients with short anterior face heights (i.e., they have flatter occlusal planes).

Step 5: Vertical Dimensions (Vertical Plane of Space). Bite depth is used to describe the vertical relationships. The possibilities are anterior open bite, anterior deep bite, posterior open bite, or posterior collapsed bite in the case of a mutilated dentition. Again, one must determine whether the problem is skeletal, dentoalveolar, or a combination. A steep mandibular plane, 35 degrees or greater to the Frankfort plane, usually represents an open bite tendency. A depression in the lower border of the mandible (antegonial notching) just anterior to the gonial angle also indicates a skeletal open bite tendency and a mandible, which rotates backward during growth. The occlusal plane is evaluated in relation to the true horizontal plane established as a perpendicular from the true vertical plane when the individual is in the NHP. This can be judged as flat (parallel to true horizontal), normal (slightly inclined posteriorly), or steep (sharply inclined posteriorly). As mentioned, the relative flatness or steepness of these planes often corresponds with vertical facial height, open bites often accompany steeper occlusal planes, and deep bites go along with flatter occlusal planes.

Classification can be accomplished clinically, without the aid of a cephalogram, simply by careful observation of the patient's occlusion and facial appearance. Whether there is a skeletal as well as dental component in each one of the characteristics is a matter of judgment. It is a sound practice to estimate those relationships that can later be measured on the cephalogram. When the orthodontist trains himself or herself to make these judgments at the initial examination, and to substantiate the clinical original estimate from the radiographic cephalometric analysis, diagnosis becomes a more natural process. It has been demonstrated that the diagnosis of a Class III skeletal pattern can be made just as well from profile photographs as with lateral cephalograms.[80]

Although dental impressions are still taken almost routinely, all records should be taken only when indicated. Surely all prospective patients require a panoramic radiograph; however, if a patient has a Class I malocclusion with crowding and an excellent skeletal pattern (estimated from the examination of facial form), it is questionable whether a cephalogram is of any real diagnostic value. It may be of considerable value, however, if one wants to assess the results of treatment or to study growth. Many years ago, Tom Graber, the editor of earlier editions of this textbook, facetiously referred to blind adherence to cephalometric "norms" in orthodontic diagnosis as the "numbers racket." Should every patient be treated to bring him or her within the range of cephalometric norms, or to ideal occlusion as defined by Angle more than a century ago? Of course not—the goal should be to optimize that patient's condition while taking into account the primary goal for that individual.

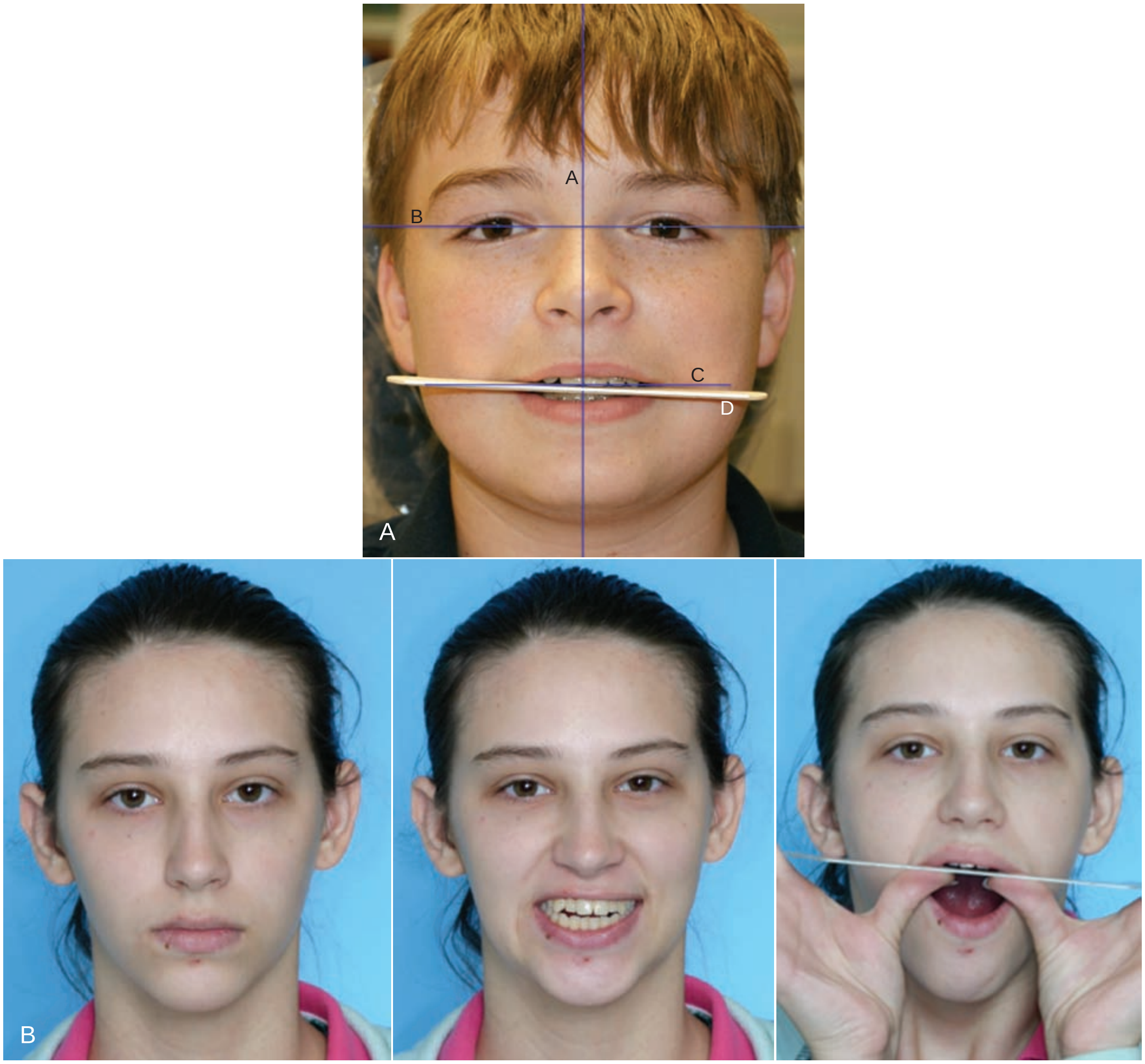


FIGURE 1-22 Determining the anteroposterior and lateral cants of the occlusal plane (pitch and roll) is important in diagnosis and treatment planning, particularly since we have the means today via skeletal anchorage to alter occlusal plane cants without having to resort to orthognathic surgery. There are two useful methods for ascertaining occlusal plane cants. One is a tongue depressor (**A**), and the other is a Fox plane (**B**). Certainly the tongue depressor is more convenient because it is disposable, but for complex occlusal plane cants, particularly in the posterior region, there still is not a good substitute for the Fox plane. It is hoped that in the era of three-dimensional imaging there will be new and more precise ways of measuring these types of cants and asymmetries.

Cephalometrics as an Aid in Evaluating Skeletal and Dental Relationships

It is not possible to establish the true nature of a malocclusion without information about the underlying skeletal relationships, and this cannot be gained from the dental casts or photographs. Prior to cephalometric analysis, these relationships were evaluated (and usually quite well) from the patient's soft tissue profile and general appearance. Cephalometric analysis in modern usage provides more detail about these points, but even it should not completely supplant a careful clinical evaluation of the patient. At best, a cephalogram is merely a static two-dimensional representation of the hard tissues involved in a complex three-dimensional system.

Evaluating many dental and skeletal relationships and selecting those measurements that were most useful in differentiating patients who fell into the different Angle classifications produced the original cephalometric analyses. With the proliferation of named analyses in the 1950s, analyses began to become ends in themselves instead of guides in making decisions about relationships. Because the typical cephalometric analysis chooses one or two specific measurements from the multitude of measurements that might be used to evaluate a single criterion, there is not and will not be any single analysis that is ideal for every patient. Instead, certain measurements will be useful in providing information about certain patients but not so useful for others. For some individuals, a detailed cephalometric workup, using measurements taken from many different cephalometric analyses, will be necessary. For other patients, it will not be necessary to make any measurements on the cephalometric film to arrive at an accurate diagnosis and reasonable treatment plan. The advent of computerized cephalometric tracing and analysis has made it extremely easy to assess a cephalometric radiograph using many different analyses. For detailed information about cephalometric landmarks and cephalometric analyses, the reader is referred to the popular textbook by Jacobson and Caufield[81] and Chapter 6 in *Contemporary Orthodontics*.[1]

In this chapter, we wish to emphasize that it is the underlying relationships, not any particular set of measurements, that should be evaluated for a given patient. This concept is most easily grasped in terms of block diagrams of the relationships in question. As shown in Figure 1-4, there are five key units in understanding anteroposterior and vertical relationships: the cranial base, the maxilla, maxillary dentition, mandibular dentition, and the mandible. Although orthodontists are primarily concerned with the position of the teeth and the jaws, it must be kept in mind that there is no certainty that the cranial base will have escaped malformation in individuals who have deviations from ideal proportion elsewhere. It is safe to say that the greater the malocclusion severity, the greater is the chance that there will be deviations in the cranial base as well as in the jaws and the teeth. The concept of potential dental and skeletal counterpart compensations is best described by Enlow's classic diagram (Figure 1-23). Enlow's concept is that there are compensatory dental and skeletal changes that take place in the growing and developing dentofacial complex. This is true in developing normal occlusions as well as malocclusions. In short, without dental and skeletal counterpart compensations for underlying jaw disproportions, malocclusion results.

A brief description of the type of information regarding the anteroposterior and vertical dental and skeletal relationships that can be gleaned from a lateral head plate is discussed next.

Evaluation of Class II Malocclusion. In any patient, a Class II relationship may be due to a combination of four major factors: (1) maxillary skeletal excess, (2) maxillary dental excess, (3) mandibular skeletal deficiency, and (4) mandibular dental deficiency. Similarly, Class III malocclusion could be caused by any combination of the reverse of these factors. Each of these excesses and deficiencies can be described as follows:

Recognition of Maxillary Skeletal Excess. This condition can also be called midface protrusion, and the increased facial convexity, which accompanies this, is one of the easy ways to recognize it. Frequently, nasal prominence, heavy orbital and malar ridges, and increased convexity of the facial profile will display true midface protrusion.

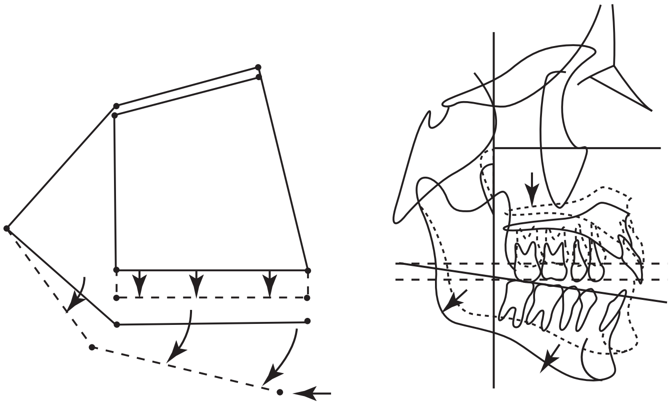


FIGURE 1-23 Enlow proposed that without dental and skeletal counterpart compensations for underlying jaw disproportions, malocclusion results. This example shows a hypothetical situation simulating exuberant vertical growth of the maxillae and dentoalveolus, which in turn caused the mandible to rotate backward, causing a concomitant anteroposterior jaw discrepancy with no dental compensation and producing a Class II skeletal and dental open bite malocclusion. *(From Enlow DH:* Essentials of facial growth*, ed 4, Philadelphia, 1996, WB Saunders.)*

Recognition of Maxillary Dental Excess. Unless there is a compensating malposition of the maxillary dentition, skeletal maxillary excess or midface protrusion will have a naturally accompanying maxillary dental protrusion as well. Once the relationship of the maxilla to the cranial base has been examined, it is necessary to examine additionally only the relationship of the maxillary dentition to the overlying maxilla on the film.

Recognition of Mandibular Skeletal Deficiency. Since Angle's concepts continue to color our view of the primary anatomic cause of Class II malocclusion, there has been a concentration of attention on mandibular deficiency. The dental occlusion would be the same whether the mandible were small in absolute terms, of reasonably normal size but positioned distally, or rotated so that its effective length was reduced. The latter situation represents an interaction between sagittal and vertical components. McNamara's method of cephalometric evaluation can be credited with making orthodontists aware of the fact that more Class II malocclusions result from mandibular deficiency than maxillary excess.[82] A patient can have Class I occlusion as the result of overclosure of the mandible with short lower face height and a dental deep bite. These individuals are said to have "masked" Class II skeletal patterns. Using Enlow's terminology, these people have had compensatory counterpart alterations in the sagittal and vertical relationships of the teeth and jaws masking the true nature of the problem.

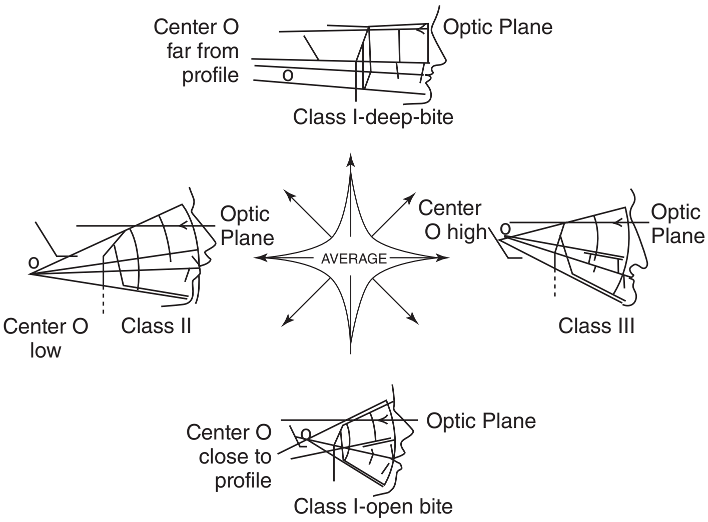


FIGURE 1-24 Sassouni's major contribution to cephalometric analysis was his observation that the relative parallelness or convergence of the horizontal planes of the face (i.e., the anterior cranial base, palatal plane, occlusal plane, and mandibular plane) are related to anterior and posterior face height and frequently reflects a tendency toward deep bite or open bite, as seen in Sassouni's original diagram. The more parallel the planes, the greater is the deep bite tendency. His "Center O" (outlined in *yellow*) is the approximation of where the planes converge posteriorly. The theory is that the farther Center O is from the profile, the less convergent are the planes. This is seen most dramatically in the Class I deep bite and open bite representations. Note that the profiles in this schematic drawing coincide with those in Figure 1-20. *(Modified from Sassouni V: The Class II syndrome: differential diagnosis and treatment,* Angle Orthod *40:334–341, 1970).*

Recognition of Mandibular Dental Deficiency. Mandibular dental deficiency is obvious from the dental casts where there are either small or missing teeth or both. It is possible for the dentition to be relatively deficient, however, in terms of being positioned distally on the mandible. In Class II malocclusion, this can occur simultaneously with protrusion of maxillary incisors as one often finds in inveterate thumb suckers.

Evaluation of Class III Malocclusion. The same measurements apply, of course, when the direction of the deviation is reversed. The recognition of maxillary skeletal deficiency or midface retrusion is particularly difficult when using traditional cephalometric analyses. A mandible, which is rotated and overclosed, can simulate mandibular skeletal excess, just as mandibular deficiency results from too much vertical opening. Thus, the real anteroposterior relationships are "masked" by the vertical relationships. This possibility must be considered in evaluating Class III problems. The interaction between the sagittal and vertical planes of space, which occurs in this fashion, makes it important to consider carefully the effect of the vertical on sagittal relationships.

Recognition of Vertical Skeletal Problems. The Angle classification focused cephalometric attention on the anteroposterior plane of space and directed attention away from the vertical plane of space. Much work has been spent on correcting this disproportionate emphasis on the anteroposterior at the expense of the vertical, but cephalometric standards for vertical relationships remain less well developed than anteroposterior standards.

Four major vertical problems exist: (1) anterior open bite, (2) anterior deep bite, (3) posterior open bite, and (4) posterior collapsed bite with overclosure. As with the sagittal and transverse planes of space skeletal and dental effects must be distinguished to make an accurate evaluation of the situation. Because bite depth is determined by the contact relationships of the teeth, the terms "skeletal open bite" or "skeletal deep bite," in a sense, are inherent contradictions.

It is in the area of skeletal vertical problems that a strong interaction with sagittal relationships occurs. This, of course, is due to rotational closure of the mandible, with the chin becoming more prominent as it moves closer to the nose. If all other things are equal, an overclosed mandible will be prognathic in appearance while an overopened mandible will be retrognathic.

This leads to the first method for detection of vertical dysplasia, namely, measuring anterior face height. Both anterior and posterior skeletal vertical dimensions need to be examined, however, and analysis of the posterior vertical is not done easily. No outstanding method of establishing posterior vertical standards has yet emerged.

Another method for evaluating vertical proportions relies on the convergence or parallelness of the mandibular plane, occlusal plane, and palatal plane, as suggested by Sassouni[83] (Figure 1-24). If these three planes converge acutely and meet at a point close behind the face, posterior vertical dimensions are relatively smaller than anterior vertical ones. This produces a skeletal tendency toward anterior open bite, which is now routinely called "skeletal open bite." It also implies a short ramus and an obtuse gonial angle, although these features do not necessarily have to be present. The open bite tendency is accentuated if the palatal plane is tipped up anteriorly and down posteriorly, a condition that is seen often enough to demonstrate that the skeletal problems leading to open bite are not exclusively in mandibular positioning. Palatal, occlusal, and mandibular planes, which run almost parallel, on the other hand, lead to a skeletal predilection toward anterior deep bite. Individuals with this condition tend to have a longer ramus and a nearly right angle gonial angle. The Wits cephalometric analysis[84] recognizes that the relationship of the anteroposterior cant (pitch) of the occlusal plane in relationship to the maxillae and mandible offers a strong clue about the sagittal relationship of the jaws.

The interaction between sagittal and vertical factors is perhaps nowhere seen better than in the person who has a short ramus, steep and convergent mandibular plane angle, and a Class II malocclusion including elements of true as well as relative mandibular deficiency. The label is Class II malocclusion in such a patient, but the problem is frequently more a vertical than a horizontal one. Especially as such patients reach their adult years, even surgical correction can be very difficult and relapse tendencies can be great. The interaction between sagittal and vertical problems extends into an interaction between these factors and the structure of the cranial base.

Recognition of Vertical Dental Problems. Dental vertical problems refer to too much or too little eruption of teeth in relation to their own supporting bone. A common example is the supereruption of mandibular incisors, which is the usual concomitant of Class II malocclusion in almost any circumstance. The lower incisors continue to erupt past the anteriorly positioned upper incisors and frequently contact the palate. If there are no skeletal vertical disproportions, this will be observed as a lengthening of the distance from the apex of the mandibular incisor roots to the lower border of the mandible.

Similarly, an open bite may be caused by infraeruption of incisors in either arch. This can be seen cephalometrically by a decrease in the distance from the incisor to the mandibular plane or palatal plane. Overall, proportions must be taken into account in judging these factors, because supraeruption of posterior teeth is also a factor in open bites. The relationship of the upper molar roots to the height of the palatal vault, which is easily observed cephalometrically, can be a great help in evaluation. The root apices of the upper molar in an adult should be at 2 to 3 mm below the height of the palatal vault. Distances in excess of this might represent some supraeruption of the upper molar, while roots, which are above the height of the palatal vault, can represent a deficiency in vertical development.

If anterior teeth meet and posterior teeth do not, there is by definition a posterior open bite, which is almost always related to failure of dentoalveolar development in one or both arches. If there is infraocclusion of posterior teeth, the orthodontist must rule out the possibility of primary failure of eruption (PFE),[85–87] which at the present time has no orthodontic or surgical remedy. PFE is characterized by a nonsyndromic eruption failure of secondary teeth in the absence of mechanical obstruction. The hallmark features of this condition are (1) infraocclusion of affected teeth, (2) increasing significant posterior open bite malocclusion accompanying normal vertical facial growth, and (3) inability to move affected teeth orthodontically.

If anterior teeth are not present and posterior dental vertical development is deficient, the result will be an overclosure of the mandible, which can be established by evaluating anterior proportions and also by checking the rest position of the mandible.

Triage and Supplemental Records

There are four major treatment-planning decisions in orthodontics, which are largely related to the severity and complexity of the orthodontic condition:

1. Will extractions be required to resolve crowding or to camouflage an underlying skeletal discrepancy?
2. Will dentofacial orthopedics and/or skeletal anchorage be required to correct a significant morphological deviation from the theoretical ideal?
3. Will surgical repositioning of one or both jaws be required to achieve the anatomical and esthetic goals of treatment?
4. Will interdisciplinary or multidisciplinary care be required to address the oral health and appearance needs of the patient?

The answers to these questions will largely determine the complexity of the orthodontic decision-making process. The more complex the problem, the greater is the likelihood that additional imaging and clinical testing will be required before a definitive treatment decision can be made. For instance, an orthodontic condition characterized by normal occlusion yet with mild maxillary and mandibular crowding or spacing undoubtedly requires no additional records than photographs and a panoramic radiograph. On the other extreme, a several skeletal Class II or Class III problem requiring surgical correction will very likely require many supplemental records including a CBCT.

One of the objectives of the clinical examination is to determine what additional records are needed to complete the database. Not so long ago it was customary to take "complete orthodontic records" as part of every orthodontic work-up. Today, there are only three records that are considered a minimal requirement in establishing an orthodontic database. These are facial and intraoral photographs, a panoramic radiograph, and, for patients with an underlying jaw disproportion, a cephalogram. The current standard regarding records is to individualize supplemental records according to the nature of the patient's orthodontic condition and the practitioner's requirements for making informed and prudent decisions regarding treatment.

Supplemental records fall into three categories:

Dental Casts. Until recently, dental impressions were taken routinely for orthodontic patients and dental casts poured in stone were carefully trimmed and polished to become an important part of the patient's records. Over years of practice, orthodontists ended up with thousands of stone models, which became a storage and disposal problem.

This has changed in three ways:

1. For patients with simple problems, casts often are replaced with high-quality digital photographs.
2. For more complex cases, stone casts are being replaced by virtual models, created from laser scans of dental impressions or casts. These can be rotated on a computer screen to allow a view of the dentition from any angle, as physical casts can be, and measurements can be made more conveniently on the computer screen than from a real stone model.[21] A major use of dental casts has been to check space required versus space available in mixed dentition patients, as well as to evaluate the compatibility of tooth sizes (Bolton analysis).[88] Both can be performed more quickly and easily using virtual models.
3. Post-treatment models often are eliminated now, simply because even for complex cases, the models are useful largely for diagnosis and are less useful in evaluating treatment outcomes. Digital photographs can provide much, if not all, the information needed to compare pre- and post-treatment alignment and occlusion.

Articulator-mounted casts remain important in planning complex restorative and prosthodontic treatment. When should the orthodontist take a facebow transfer and mount casts on an articulator? That has been a controversial point for years, with some clinicians insisting that mounted casts are necessary for all orthodontic patients, while the majority reject this view and mount casts only occasionally.

The problem with articulator-mounted casts in orthodontics is the assumption that the distance from the dentition to the TMJs remains the same from one time point to another so that sequential mounted casts can show details of changes in occlusion. This is true for adults, but not for children and adolescents, who represent the majority of orthodontic patients. For that reason, mounted casts are obtained as part of the orthodontic database primarily for adults who have a major CR/CO discrepancy and will have restorative treatment in addition to orthodontics, or who will have maxillary surgery that changes vertical dimensions.

Lateral Cephalometric Radiographs. An important question is whether a lateral cephalometric radiograph is needed. Often the facial and jaw proportions are apparent in the clinical examination, so that the patient can be told about jaw relationships and tooth-lip relationships. Why, then, is a ceph desirable? Although an adequate diagnosis may not require it, it is impossible to evaluate treatment progress for patients whose jaw relationships or incisor positions will change during treatment without being able to superimpose cephalometric tracings. For that reason many patients benefit from potential improvement in quality of treatment provided by having a pre-treatment lateral cephalometric radiograph.

Other Radiographs: Three-Dimensional Imaging. Posteroanterior (frontal) cephalograms cannot be superimposed as accurately as lateral cephalograms and are ordered as supplemental diagnostic records primarily for patients with facial asymmetry or marked maxillary constriction. TMJ radiographs rarely are indicated. For patients with TMJ problems, MRI images are more useful, and if radiographic images of the joint(s) are needed, tomographic images provide much more information than standard radiographs of TMJs.

Three-dimensional images created by computed tomography (CT) have been used in medicine for many years now but were not used in evaluating orthodontic patients until recently for two reasons: the radiation dose and the cost. The advent of CBCT of the head has reduced both radiation and cost, to the point that CBCT is practical for patients who would benefit from using it. Although CBCT can be a useful clinical tool, many of its current applications are in research and teaching and do not yet have clinical applications. The reader is referred to Chapters 4 and 20 of this text to learn more about the current state of the art and promise of these three-dimensional technologies.

Summary of Diagnosis in Orthodontics

Diagnosis in orthodontics begins with an adequate database derived from three sources: (1) questionnaire and interview data consisting of medical, dental, and psychosocial history; (2) clinical examination data including a preliminary classification of dentofacial traits; and (3) orthodontic records. Once the database is constructed, a list of problems, with each outlined as accurately and concisely as possible, serves as the diagnosis. The treatment plan is the connecting link between diagnosis and therapy, in which the orthodontist establishes a "blueprint," or work plan, for resolving the problems.

The decision-making process in orthodontics requires more than an abbreviated labeling of the problem and the name of a "regulating device" for its correction. We hope the reader will become convinced that diagnosis in orthodontics is not simply classification and that treatment planning is not just appliance design. Too often orthodontists offer, for example, *Diagnosis: Class II, Division 1; Treatment Plan: Damon.* Although this type of shortcut works satisfactorily for a large proportion of patients in practice, it does not serve well for an individual with a complex orthodontic condition. Such a "diagnosis" in this example does not adequately describe the nature of the problem and the name of an appliance is not a substitute for a detailed treatment strategy. We present here a method of viewing the patient and attendant orthodontic condition in such a way that rational and appropriate treatment decisions can be made.

For instance, if as in the previous example, the problem is a Class II molar relationship on a dental and skeletal basis, this observation is one of the priorities on the problem and thus part of the diagnosis. One of the treatment alternatives for addressing the problem in a growing patient would be "restraining" maxillary growth. Thus, the treatment plan might be to apply orthopedic force to the maxilla via the maxillary molar teeth, and the force might be applied best in a posterior and superior direction. This would constitute the biomechanical considerations. The mechanotherapy might be a "high pull" headgear or skeletal anchorage to fulfill these biomechanical objectives. In short, once a problem is identified, a solution to that problem is considered (i.e., a treatment plan is established and then a mechanotherapy is selected to carry out the biomechanical requirements). This is what is meant by the problem-oriented approach in the orthodontic decision-making process.

TREATMENT PLANNING

Problem-Oriented Approach

Prioritization and Treatment Possibilities. Once a discrete list of problems has been established, the orthodontist must consider the interaction between the problems and their potential solutions, because all of the factors eventually must be integrated into a unified treatment plan. Having separated the problems in a prioritized problem list, it is important to systematically put them back together and to consider the impact of one effect on the other.

For instance, if two of a patient's problems are maxillary constriction with bilateral maxillary palatal crossbite and excessive vertical height of the face accompanied by an anterior open bite, the potential solutions to these two problems may not be compatible. In this example, maxillary expansion to correct the crossbite may increase vertical face height, which in turn may exacerbate the anterior open bite. This is what is meant by an interaction and is well demonstrated in Case Study 1-2 (See Figure 1-28). The type of interaction just described would be considered unfavorable. It is a far happier circumstance if correcting one problem also addresses another problem on the list. The reason for breaking the problems down into the same five categories as the five characteristics required to describe any orthodontic condition is to bring order to the process.

Establishing priorities for problem lists requires consideration of the extent of deviation from the theoretical ideal, the relative treatment difficulty that might be encountered in correcting the problem, and the priority the patient or parent places on the characteristic. One begins generating tentative treatment plans for individual problems, starting with the most severe or difficult problem first and ending with the least severe. There are two major advantages to this "individual problem–individual plan" approach before a final synthesis into a unified plan takes place. The first is that there is less chance of rejecting a treatment possibility too soon or never thinking of it at all. The second, which is even more important, is that this approach allows the orthodontist to keep the patient's various problems in perspective as to their priority in treatment. The reason for listing the problems in priority fashion is that, because compromises are invariably necessary in treatment planning, it is important that the most relevant issues are favored at the sacrifice of less significant factors. With our fetish about achieving theoretically ideal occlusion, we as orthodontists sometimes overlook the patient's "chief concern" because of our compulsion about how the teeth fit. We must satisfy not only ourselves but the patient as well.

A tentative treatment plan is merely a rational approach to correcting the problem, as it is perceived. It should be emphasized that the tentative treatment plan is the general strategy of treatment, such as tooth extractions, orthopedics, surgical orthodontics, functional orthodontics, or control of tooth eruption. The treatment strategy is then translated into biomechanical terms and a specific mechanotherapy is prescribed.

For example, refer to the patient records shown in Case Study 1-2. The crowding, and the patient's concern about it, gives the alignment problem a high priority. Tentative treatment plans are immediately suggested by this listing of problems: extraction of a dental unit in all quadrants to solve the crowding or reducing the mesiodistal widths of maxillary teeth or an asymmetric extraction pattern to deal with the tooth-size discrepancy. It should be clear in this example that it would require complex force systems and multibonded appliances to carry out this treatment plan. Obviously, before an overall treatment plan can be written and a precise course of action outlined, all of the other problems and their tentative solutions and interactions must be considered.

Depending on the relative compatibility or incompatibility of the tentative treatment plans (interactions) and any compromises that may be deemed necessary based on the potential for full correction of the problem (therapeutic modifiability), the tentative treatment plans are then synthesized into a unified treatment plan. The procedure for doing this is to examine the tentative solutions to the most severe problem and select the one that gives the greatest benefit to the patient with the least impact on other problems. This process is repeated for each of the problems, attempting to maximize the benefit to the patient at each stage until a detailed approach, including the mechanotherapy has been achieved. If solving one problem makes another worse and a compromise is necessary, the decision is made on the dual basis of maximizing cost-benefit and solving the more serious problem first if possible.

To Extract or Not to Extract?

The major consideration in this important decision relates to management of crowding/protrusion (which can be considered two aspects of the same thing) and the possibility of camouflage for skeletal problems.

Crowding/Protrusion. If a patient presents with severe crowding, extremely procumbent maxillary and mandibular incisors, marked facial convexity, and severe lip protrusion, it should be obvious that removing premolars to alleviate crowding and to allow for the retraction of anterior teeth is the best strategy for solving the problem. Unfortunately, most patients do not present such a clear-cut choice. It is for this reason the extraction versus expansion debate has raged in orthodontics for more than 100 years.[89] To better understand the grounds for the debate, we must consider the pros and cons of dental arch expansion.

There are three reasons why an orthodontist cannot under usual circumstances significantly expand the dental arches. First, the tissues over the labial surfaces of the teeth cannot usually tolerate the teeth being moved into a more facial position. Bone tends to resorb vertically or, if the roots are moved out in advance of the rest of the teeth, fenestration or dehiscence of the labial cortical plate occurs. If a dehiscence is produced, the gingiva in later life may recede in that area.

The second reason the orthodontist is limited in the amount that he or she can expand the arches is that the teeth will be unstable if they are moved labially or buccally "off their bony bases"[90,91] and into positions where the soft tissue equilibrium can no longer be maintained. The intermolar and especially the intercanine widths for the most part have to be maintained close to their original dimensions during and after treatment, although it is not possible to predict arch stability on the basis of arch dimensions alone[92,93](see Chapter 27). A distillation of clinical experience suggests that expansion of mandibular intercanine width creates instability of the lower incisors. Depending on the initial incisor position, slight incisor advancement may be tolerated by their bony support and soft tissue constraints. Somewhat more lateral expansion in the premolar area may be tolerated than in the molar region (Figure 1-25).

Third, major dental arch expansion, particularly in an anterior direction, can have an adverse effect on facial appearance. It is simply not true that arch expansion always creates a more esthetic treatment outcome. It is rare that an already convex face that has been made more convex as a result of orthodontic treatment becomes more attractive. The same can be said for a concave face. Retracting teeth orthodontically can make the profile more concave, and there is little likelihood that there will be esthetic benefit to the patients. Thus, the general rule in regard to profile is "the principle of opposites." If a profile is convex, consider whether making it less convex would enhance facial appearance, and if a profile is concave, consider whether making it less concave would be an enhancement.

Incisor Repositioning for Camouflage. Changing the positions of anterior teeth to compensate for an underlying skeletal disproportion is called "camouflaging the skeletal discrepancy." In minor skeletal disproportions, it almost always makes more sense to camouflage the discrepancy with tooth movement rather than invoking orthognathic surgery. On the other hand, if a major skeletal disproportion is accompanied by a significant

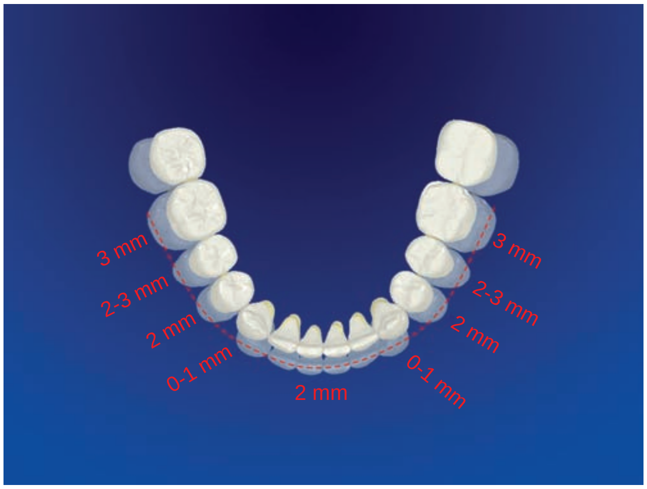


FIGURE 1-25 The amount of dental expansion one can safely achieve with orthodontics is related to three major factors: *1,* stability determined largely by the soft tissues; *2,* appearance, particularly in regard to profile; and *3,* the periodontium, particularly the labial cortical plate of bone and the amount of attached gingivae on the facial aspects of the tooth roots. These constraints make it infeasible to move the mandibular teeth facially more than 2 to 3 mm. To do otherwise would simply be an invitation for instability, unfavorable facial changes, and unfortunate periodontal sequelae. Of course, there are exceptions to every rule.

facial imbalance, there is a limit to the amount that the situation can be effectively camouflaged with orthodontics alone. This realization is what caused orthodontists to reject Angle's dogmatic proscription against tooth extractions and ultimately led to the development of orthognathic surgery.

The importance of the mandibular incisor position in relation to basal bone and to the face was recognized by Tweed and led him to reintroduce extractions into orthodontics. Even before cephalometrics became a clinical tool in orthodontics, Tweed[94] realized that there was an important relationship between the inclination of the mandibular incisors (IMPA) and the mandibular plane angle (MPA). The steeper the mandibular plane, the more effectively procumbent become the mandibular incisors. Thus, retraction of the mandibular incisor teeth can be important for both facial esthetics and stability of the teeth. If the mandibular teeth are crowded as well as too far forward, one has to take both of these factors into consideration in establishing a treatment plan.

At the tentative treatment plan stage, a key decision is establishing a target for the anteroposterior position of the incisors after treatment. If the incisors do not provide enough lip support and this is a major problem, they can and should be proclined, but it must be recognized that periodontal health becomes an important consideration and that permanent retention will be required. If the incisors are too protrusive, so that lip separation at rest is apparent, the retraction requirements can be defined as the degree to which they have to be retracted: minimum, moderate, and maximum retraction. This defines the amount of extraction space required for retraction of the anterior teeth. Minimum retraction problems are those problems in which only part of the extraction space in both arches is needed for retraction. Moderate retraction problems require only part of the mandibular space but most of the maxillary space. Maximum retraction problems require all of the extraction space in both arches for the retraction of the incisors. Sometimes it is necessary to define the retraction requirements for each arch separately. The retraction requirements to a great extent influence the decision regarding which teeth are to be extracted and whether skeletal anchorage might be required.

In the past, a method of representing treatment goals two-dimensionally (sagittally and vertically) was by simulating the proposed skeletal and dental changes on the cephalometric tracing and estimating the facial soft tissue changes, which would likely result. This approach produced a VTO (visualized treatment objective) or "blueprint," which could be carried out through the appropriate mechanotherapy. This was particularly effective in planning treatment for nongrowing patients (adults) and for planning surgical treatment. It was and is somewhat more difficult to accomplish for the growing patient because of the limitations in our ability to forecast growth. This does not diminish the importance of attempting to adopt this kind of thinking in treatment planning. The original work of Ricketts[95] and Walker[96] in using the computer to simulate growth is noteworthy; however, with the current use of computer imaging and algorithms representing the soft tissue changes that are likely to result from underlying hard tissue changes, the orthodontist can better predict the potential outcome of treatment, particularly from a profile standpoint. A major advantage of using computer imaging in this way is that the imaging can be shown to the patient in interactive fashion (see Case Study 1-2). It has been demonstrated that surgical patient's self-image is more likely to be greater after treatment if he or she was shown this type of prediction prior to surgery.[97]

To satisfy the criteria of "improved dentofacial appearance and reasonable stability," one frequently must consider extracting teeth. Case observed that no matter how irregular the teeth, however bunched, malaligned or malposed, they could always be placed in their respective places in the arch and in normal occlusion; therefore, so far as the relations of the teeth to each other are concerned, no dental malposition should be taken as a basis for extraction. The only excuse then for the extraction of savable teeth must be that it is inexpedient or impossible to correct their positions in that way without producing facial protrusion.[89]

The only thing that we would currently add to Case's dictum is that, in some cases, aligning malposed teeth without extraction might markedly affect the stability of the denture. Unfortunately, we have not yet learned how many of our expansion cases we can say with assurance might be stable (compared with the stability of the same cases treated with extraction) in the long term.

If we accept appearance and stability as the valid criteria for extraction in orthodontics, how well can we determine a priori in a child what the face will look like later on in adulthood and what the new functional environment will be after treatment? Part of the answer was pointed out by Tweed, although his interpretation was incomplete. He found that a group of patients whom he had treated without extractions showed a great tendency toward dental collapse. Because these dentitions had been expanded during treatment, he correctly reasoned that in those cases there was a greater tendency toward contraction of the arches than toward slight growth (expansion). Under the circumstances, he removed teeth in these patients and closed spaces in a situation in which he had already therapeutically determined that extraction rather than expansion was indicated.

In these same patients, Tweed also therapeutically determined that the forward expansion of the dental arches had harmed the patients' profiles. After retreatment with extraction, according to Tweed's tastes, these patients' profiles were much improved. One cannot always make this extraction decision on an a priori basis. In how many cases in which teeth have been extracted has facial appearance been less pleasing after treatment? One cannot always predict what the face and profile would look like after extracting teeth. There are mixed dentition cases in which an orthodontist has performed serial extractions only to find later that sufficient space, over and above the extraction space, has developed for all of the permanent teeth.

In orthodontics we have tended to be extreme in our views regarding extractions. At one time it was a sin to extract in any case, and later nearly all irregularities became extraction cases. For a number of years, orthodontists considered that there were only a few "borderline" cases in which a decision to extract or not to extract was somewhat difficult. It is rather unsettling that the "borderline" category probably encompasses more cases than we ever suspected. Ultimately, facial appearance is affected by the growth of several structures (soft tissue, nose, chin), which, at this time, we cannot neither govern nor predict. Stability of the denture depends on factors about which we know little and have little control. If we do not know the cause of malocclusion, unless we remove the etiologic factors by chance, there is reason to expect "physiologic recovery" (relapse). Indeed, the dimension of diagnosis that is most related to postretention stability is the determination of the cause of the malocclusion.

Factors in Evaluating Treatment Possibilities

Critical questions in evaluating treatment possibilities, of course, revolve around the extent of change that is possible and that is affected by changes at both the skeletal and dental levels.

Growth Potential. Orthodontists have long known that it is far easier to treat patients who have underlying skeletal discrepancies while they are still growing. It has also been clear that the best treatment results are attained in patients whose facial growth patterns are favorable. In a Class II skeletal pattern with mandibular retrognathia, a favorable growth pattern is represented by a mandible that grows more forward than downward. In a Class III skeletal pattern, a favorable growth trend is for the mandible to grow more downward than forward, hopefully with a backward rotating pattern. In designing treatment plans, the orthodontist must take into consideration growth potential, and every effort is made to enhance the growth pattern, while minimizing any tooth movement that might have an unfavorable impact on facial growth.

The concepts of Bjork and Skieller[98] related to forward and backward rotating growth patterns have markedly improved our previous understanding of facial growth patterns. With this newer information, it is not reliable to interpret the "constancy of growth pattern" concepts of Broadbent[62] and Brodie[99] too literally, because it is now clear that increments of facial growth are not necessarily uniform in either direction or rate. Even the paths of eruption of the teeth are quite variable and difficult to predict; however, since the average trend in facial growth is more or less constant, the idea still serves as a suitable way to characterize the pattern of overall facial growth.

The mechanotherapy required to achieve the goals of orthodontic treatment for adults may be considered against a background of unchanging jaw relationships, whereas in growing children the orthodontist must consider the changes that will occur as a result of growth as well as those that are caused by treatment. Growth prediction introduces another uncertainty into the diagnostic procedure. Because the control factors for skeletal and soft tissue growth are not yet known, it is no wonder that growth prediction is so uncertain when the underlying mechanisms and determinants of facial growth remain unclear. Nevertheless, assessing skeletal maturation by analyzing cervical vertebral development has largely replaced the wrist film in establishing stages of skeletal maturation in orthodontic patients[100] (see Chapter 8).

Applications of Skeletal Anchorage. There is no more fundamental principle in orthodontics than that of anchorage. Newton's third law, stating that for every action there is an equal and opposite reaction, remains the basis of all orthodontic tooth movement. To effectively move a tooth requires a more or less stable point of attachment of the force system acting on some portion of the crown of the tooth to be moved. The anchor unit must be able to resist the force without its moving, as well. The biomechanics of orthodontic tooth movement is considered in detail in Chapter 11.

The introduction of skeletal anchorage in orthodontics using a fixture (TAD) that is implanted in bone and is thus unable to move offers new possibilities for creating absolute anchorage. This innovation opens new therapeutic possibilities in orthodontics and has extended the envelope of orthodontic tooth movement. Heretofore, orthopedic devices like rapid palatal expansion appliances moved teeth as much as they did bony units. Palatal expansion with skeletal anchorage can to a great extent limit unwanted tooth movement. This is not meant to imply that skeletal anchorage is required for all palatal expansion; however, in selected patients it can have great benefit. It has been demonstrated that skeletal anchorage can be substituted for extraoral anchorage with headgear and its greatest benefit is for incisor retraction in noncompliant patients.[101]

Camouflage versus Surgery. During much of the history of orthodontics, a borderline problem was one that could be treated with or without extractions. Today, borderline can also refer to a patient who could be treated either orthodontically with the aid of skeletal anchorage or with orthognathic surgery. With skeletal anchorage, an orthodontist has greater ability to camouflage an underlying skeletal discrepancy by moving larger numbers of teeth over greater distances in an attempt to mask underlying skeletal disproportions. This topic is described further in Chapter 12. In orthodontic conditions where there is a major discrepancy in jaw proportions, the skeletal discrepancy can be addressed by surgically repositioning the jaws. Unfortunately, orthognathic surgery is being performed less and less because of greater rationing of health care dollars by the insurance industry.

For a description of the basic principles of surgical orthodontics, see Chapter 25 or refer to *Contemporary Treatment of Dentofacial Deformity*.[102]

Therapeutic Modifiability and Compromise. Moorrees and Gron[103] called the extent to which an orthodontic condition can be corrected "therapeutic modifiability." The greater the effort to achieve a small change, the less is the therapeutic modifiability, and vice versa. This is another way of asking what the "achievable optimum" is for the patient. If one can ascertain the "achievable optimum" before treatment, then reasonable goals can be set as an end point for therapy. Integrally involved with the concept of modifiability is the assessment of contraindications to treatment. An overly zealous treatment plan may result in well-aligned tooth crowns but with severe root resorption, devitalization, or fenestration of the labial cortical plate of bone.

In considering therapeutic modifiability, two points in time should be considered: the first when active treatment is complete and the second when the patient is no longer wearing any orthodontic appliances, either active or passive. If teeth are moved to unstable positions, there is a great likelihood that there will be rebound or physiologic recovery. The orthodontist must decide whether he or she wants to give the teeth a "round-trip ticket." Under some circumstances, the choice may be permanent retention. In any event, it is highly advantageous if the modifiability can be determined accurately before instituting therapy. The final treatment objectives should be based partly on the potential modifiability of the problem. As long as we continue to use the "imaginary ideal" as a baseline, all orthodontic therapy is, in a sense, compromise therapy. If it is not a compromise immediately after active treatment, it usually is a compromise postretention. Thus, since compromise is a matter of degree, it behooves the clinician to establish realistic treatment objectives before treatment commences.

The synthesis of tentative treatment plans into a unified treatment plan is illustrated in Figure 1-8 and in the case reports. For relatively simple cases, the sequence in thinking for the experienced orthodontist is almost intuitive, and so quick that the individual steps are hardly noticed. For more complex problems, the step-by-step approach is more evident and more obviously advantageous.

No treatment plan should be considered final, in the sense that "mid-course corrections" must be made throughout treatment depending on treatment response, patient cooperation, growth, or any unforeseen events.

Testing Treatment Response. A number of orthodontic diagnostic systems project a rigid treatment plan from limited cephalometric and dental cast measurements. We hope that by having offered a format for establishing and analyzing the database, creating a prioritized problem list, and offering tentative treatment options for each of the problems, we have not implied that a definitive treatment plan can be generated for all patients by using this approach. Rigid systems or definitive treatment plans succeed for the majority of patients but fail for others. Their difficulty is that of the weather forecasts of years past that said flatly "rain" or "clear." No allowance for uncertainty is made, and a definitive treatment plan is called for immediately.

There are several sources of uncertainty in orthodontic treatment plans. A major difficulty is that the cause of a malocclusion is rarely known; as long as this is the case, there must be some uncertainty in the treatment plan for correction of the problem. Although an orthodontic treatment plan is quite likely to be the same whether the malocclusion is caused by genetic influence on jaw morphology or by neuromuscular influences on tooth position, the treatment response may not be the same at all. The use of therapeutic diagnosis acknowledges that the cause of the problem is not known. For this reason, there has been a concerted effort to get away from therapeutic diagnosis in medicine. As we learn more about the etiology of malocclusion, we should also strive to perfect our diagnostic abilities in orthodontics. On the other hand, it is important to recognize that a diagnosis that does not include the cause of the problem, as many orthodontic diagnoses do not, is incomplete and leaves room for error. This is also true regarding the understanding of the potential variability of an individual's tissue reaction to orthodontic tooth movement (see Chapter 9).

One way to deal with diagnostic uncertainty is to use the treatment response as another diagnostic criterion.[104] With this procedure, an initial diagnosis is made, in the face of some uncertainty, as to the nature of the problem. An initial stage of specifically directed treatment is based on this diagnosis, and the treatment response is used to confirm or reject the original diagnosis. For instance, all interceptive procedures in orthodontics are really exercises in therapeutic diagnosis. If a deformity is resolved with the use of a device such as a thumb habit/tongue-guard appliance, the indictment of a habit as the cause of the open bite is confirmed. If the malocclusion persists, then a new hypothesis or diagnosis must be formulated and a new treatment plan established.

Therapeutic diagnosis is not a substitute for established diagnostic procedures, nor should it become a cover for fuzzy thinking in diagnosis. Where uncertainty exists despite a careful diagnostic evaluation, however, there is danger in formulating a rigid treatment plan. Systematic evaluation of the initial response to orthodontic treatment can help a great deal in making difficult diagnostic and treatment-planning decisions, especially concerning the basic question of extraction or nonextraction treatment. Borderline extraction cases, in which the treatment response should be considered before one decides to extract, are more common than many diagnostic systems indicate. It is strength, not weakness, to recognize true uncertainty.

From this frame of reference, much of orthodontic treatment is based on a type of therapeutic diagnosis. If a case is treated successfully (occlusally and facially) without extractions and remains stable, we assume that a correct decision was made and that some of the causes of the problem were also eliminated. If, on the other hand, nonextraction treatment proceeds with difficulty, adversely affecting facial esthetics or indicating the prospect of an unstable denture, we can then presume that extraction might alleviate the problem. When extraction cases are selected on this basis, the results are more consistently successful. It is no surprise that in these cases the residual extraction spaces close rapidly after treatment and that the facial esthetics are dramatically improved.

It is impractical to perform a therapeutic diagnosis for every orthodontic patient. First, there are many cases in which the extraction decision is clear from the start (e.g., cases of bimaxillary dentoalveolar protrusion with crowding). Second, if therapeutic diagnosis were carried to an extreme, the increase in treatment time in many cases would make the approach unrealistic. The final decision in a therapeutic diagnosis should be made within the first 6 months of treatment. The increase in treatment time is minimal if an extraction decision is made after the first few months, because the first phases of treatment in extraction and nonextraction cases involve the same basic elements of alignment and leveling.

An example of the effective use of a therapeutic trial in a borderline extraction case is shown in Figure 1-26.

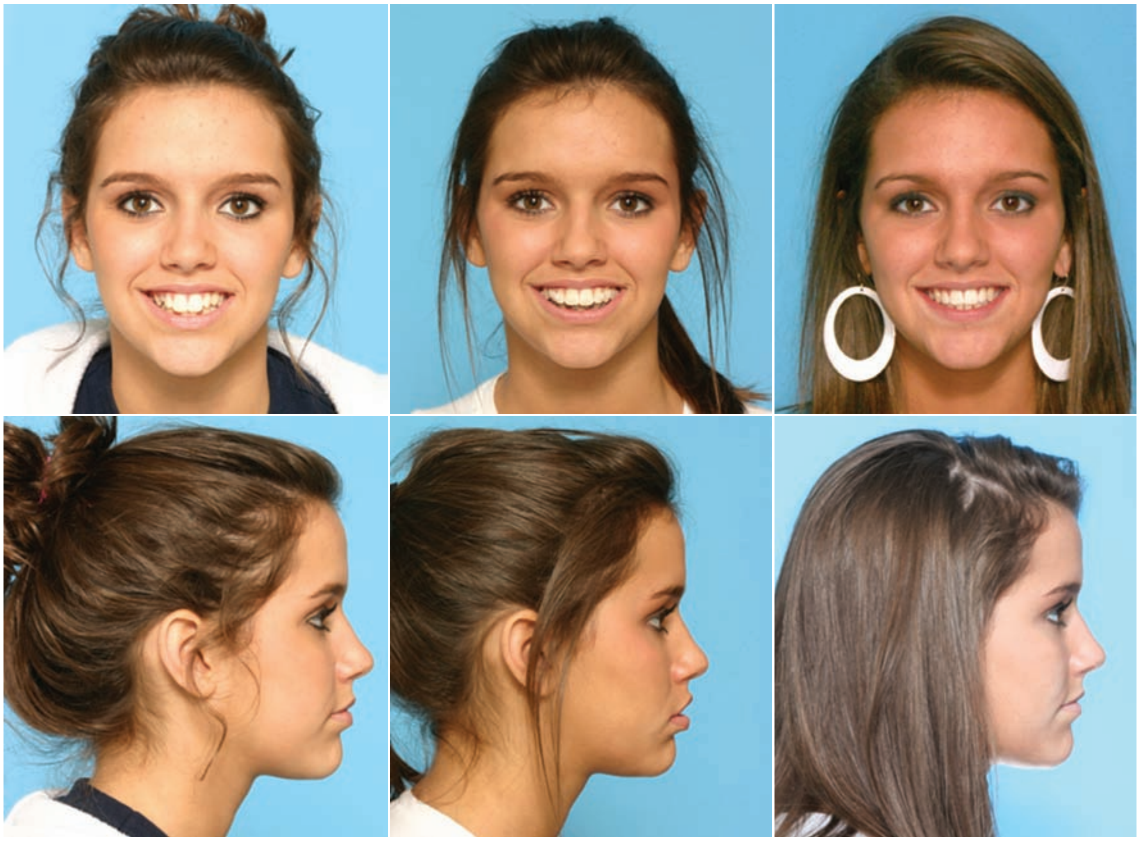


FIGURE 1-26 The decision to attempt treating this borderline extraction patient with nonextraction treatment related to her already pleasing facial balance and her attractive smile. During the course of treatment, the patient and her parents became concerned about what they saw as unfavorable changes in her dentofacial appearance related to the tooth movement. The orthodontist was concerned about the potential that the teeth might be less stable due to having moved the teeth "off basal bone" and perhaps beyond the limits of soft tissue adaptation. The patient, parent, and orthodontist jointly agreed to have four first premolars removed.

In this case the decision was made for two reasons: (1) the patient's concern about increased lip protrusion and incompetence and (2) the orthodontist's concern about stability (mandibular incisors had been significantly proclined). It should be acknowledged that in the realm of appearance these decisions often come down to judgments about appearance, and in this case the patient's and parent's concern about appearance was a major factor in determining the treatment plan, as it should be. This will be the crux of the problem with orthodontic outcomes research in the future. Judging quality of care will be considerably more difficult than meets the eye. From the scant information currently available, it appears that an orthodontist's view about the quality of outcome often differs considerably from that of the patient or parent.[105]

Assessment of the patient's cooperation with regard to wearing appliances and practicing adequate oral hygiene should not be minimized. Because our treatment plans in orthodontics always call for some type of therapy that requires the patient's diligence in wearing appliances, this is another factor that can be tested only by instituting treatment. Therapeutic diagnosis allows for the later selection of a noncompliance approach such as skeletal anchorage. If oral hygiene is poor, the hazard of decalcification becomes great. It is sometimes comforting to be able to attenuate markedly the treatment goals and reduce treatment time.

Despite these very real constraints and limitations in orthodontic diagnosis, it is possible to establish from the outset a reasonably definitive plan of treatment for most patients.

Mechanotherapy: The Last, but Not the Least, Step in Treatment. Once a unified treatment plan has been established, consideration is given to selecting a treatment method or mechanotherapy that best addresses the issues at hand. The criteria for evaluating the optimal treatment method are how effective the approach is likely to be and how efficient the method is (i.e., getting the job done with as little waste of time and energy on the part of the patient and orthodontist as possible). It is primarily from the efficiency standpoint that almost all orthodontists in practice adopt a single appliance system as the backbone of their mechanotherapy. The ease with which an appliance can be modified for specific problems and how amenable it is to adding various auxiliaries and adjuncts to treatment are the factors to be considered in selecting an appliance system. Self-ligating brackets may or may not be more effective in achieving desired results, but their greater efficiency compared with other appliances has yet to be demonstrated.[106] Nonetheless, it is important to first think about what needs to be accomplished before thinking about the type of modification of one's appliance system is required to achieve the desired outcome. Keeping the goals of treatment in mind should always precede appliance considerations. In other words, the treatment outcome should not be dictated by an appliance system. There are many different types of orthodontic appliance systems, many purporting to be a panacea for any and every type of orthodontic condition. One should always be wary of such claims.

Conceptually the thought process in translating treatment plans to mechanotherapy should proceed as follows. If a deep anterior overbite were attributable to inadequate eruption of the posterior teeth with adequate eruption of the incisor teeth, then a rational plan for a growing child would be to attempt to accomplish "differential eruption." In other words, through one's mechanotherapy an attempt should be made to inhibit the eruption of the incisor teeth and accelerate the eruption of the posterior teeth unless this would have an adverse effect on maxillary anterior tooth show in speaking and smiling. The mechanotherapy to accomplish this, of course, would be based on the other factors that require correction. If the deep bite were the only problem that the patient had, it might be advantageous to use a functional appliance for accomplishing this differential eruption because these appliances are well designed for controlling vertical movements of the erupting teeth. Depending on the severity of the problem, skeletal anchorage might be a consideration because TADs are also well suited to deal with vertical problems. The choice of mechanotherapy should be a totally rational approach to carrying out the treatment plan and achieving the treatment goals. The optimal mechanotherapy should merely be a logical biomechanical reflection of the treatment plan for dealing with each problem on the problem list.

If one of the sagittal problems is maxillary prognathism in a growing child, the treatment plan may be "restraining" maxillary growth. One might decide to apply orthopedic force to the maxilla via the maxillary molar teeth, and the force might be applied best in a posterior and superior direction. This would constitute the biomechanical considerations. The mechanotherapy might be a "high pull" headgear or skeletal anchorage to fulfill the biomechanical objectives, if that is consistent with the other goals of treatment. The final decision regarding the specific kind of headgear in this example would be determined after synthesizing all of the tentative treatment plans.

Diagnostic/Treatment-Planning Sequence: The One-, Two-, or Three-Step Approaches

Most families lead busier lives today than ever before. Along with this increasingly frenetic existence has come an even greater need for patients and parents to juggle family and work-related responsibilities. It has become more of a rule than an exception in orthodontic practice to encounter extremely busy two–working parent families. Students' extracurricular activities are often as dominant in their lives as their academic pursuits. Thus, if fewer appointments are required to commence orthodontics, it makes adjusting to treatment easier for the entire family. By reducing the number of visits needed to complete treatment, the cost of treatment can be reduced or at least maintained, which is a further benefit for the consumer. From the provider's point of view, there is merit in streamlining practice to allow for treating more patients. Seeing a new patient once rather than two or three times before appliances are placed reduces the doctor's overhead costs. Sharing the tasks involved in a new patient encounter with a treatment coordinator can usually reduce the orthodontist's time spent with the patient and parent to 20 minutes or less.

Practicing orthodontists intuitively reached the conclusion that for routine orthodontic conditions it is not necessary to have what used to be called complete orthodontic records to establish a diagnosis and treatment plan. Clinical research has shown that additional records beyond study models (or photographs) and a panoramic radiograph are often largely superfluous in that they do not alter the conclusions reached without them.[68,69] Of course this is not true for more complex problems.

With these factors in mind, what does a prospective patient or parent want to know about orthodontics from this initial encounter? Because so many parents of today's prospective orthodontic patients have themselves had treatment, they are far better informed about orthodontics than were their parents. Thus, the typical parent or patient today will generally want to know only four things from the orthodontist after the clinical examination is completed:

1. The salient characteristics of the orthodontic condition and whether the patient will profit from orthodontics in regard to appearance, function, or both?
2. What sort of appliances will be needed?
3. Will there be any special requirements such as extractions, surgical exposure of impacted teeth, TADs, or orthognathic surgery?
4. How long will treatment take?

For approximately 80% of new patients, in a typical practice, an orthodontist can answer these four questions, at least in broad outline, after the following:

- Private debriefing by the treatment coordinator regarding the patient's dental and medical history and chief concern
- A perusal of facial and intraoral photographs and panoramic radiograph already obtained by the treatment coordinator before seeing the patient
- Patient interview and clinical examination with recording of notes by the TC

For complex orthodontic conditions, although the basic treatment questions can be answered after the clinical examination, additional records (i.e., impressions for digital models and a cephalogram along with time for greater reflection) are required to establish a more detailed treatment plan. In those instances, a follow-up call or meeting with the parents can usually confirm, clarify, or modify the original plan. In a few instances such as when surgical treatment or interdisciplinary care is being considered, it is highly advantageous to schedule a patient conference.

In most offices, the cost of treatment will primarily be determined by the orthodontist's estimate of treatment time and can be presented to the patient or parent by the treatment coordinator. There also are subsidiary issues that can be covered in greater depth by the treatment coordinator such as illustrating the characteristics of the problem using the patient's photographs or panoramic radiograph, showing examples of the appliances that will be used including retainers, discussing the risks of treatment, and answering any other questions the parent or patient may have. It is not unusual for the treatment coordinator to spend another 30 minutes with the patient and parent after the orthodontist has left the examination room.

For complex orthodontic conditions, obtaining additional records such as diagnostic set-ups for suspected tooth size discrepancies, asymmetric extractions, and interdisciplinary treatment with or without surgery remains an important process. This is also true of requesting a CBCT for a patient with an impacted canine or other issue requiring further imaging. Once these supplemental diagnostic records are obtained, it almost always requires additional time for the orthodontist to analyze these data once they are available and potentially meet with another specialist regarding combined treatment. Thus, there are patients who will clearly profit from additional records and it is simply impossible to establish a definitive treatment plan at the first patient visit. For these patients, it is typical that two or three additional steps after the initial evaluation will be required before the patient/parent and orthodontist can come to an agreement on the best way to proceed. As discussed, an experienced orthodontist should nonetheless be able to outline the basic treatment alternatives at the very first encounter with the patient.

Special Problems in Treatment Planning

Specialized treatment considerations for patients requiring orthognathic surgery and/or interdisciplinary dental care are covered in Part V of this compendium. The reader is encouraged to refer to these chapters to complete one's understanding of how the basic principles outlined in this chapter apply to more complex problems.

ILLUSTRATIVE CASES

CASE STUDY 1-1 A PATIENT WITH AN ORTHODONTIC CONDITION AMENABLE TO THE ONE-STEP DIAGNOSIS AND TREATMENT-PLANNING APPROACH

Although this patient was treated in a university setting, the case report will be written as if she had been seen in private practice.

Patient History

Patient A.S. was a healthy, well-nourished, and socially well-adjusted 14-year-old Iranian American white girl who presented for an orthodontic evaluation with a chief complaint of "crooked teeth" and an "overbite" (which was interpreted to represent her 4-mm overjet). She reported no history of caries or periodontal disease. Neither of her parents had orthodontic treatment, but A.S.'s brother recently completed orthodontics, indicating that the family had a high "orthodontic IQ."

Initial Records

Photographs and a panoramic radiograph were obtained by the treatment coordinator before the clinical examination by the orthodontist (see Figure 1-27, *A* and *B*). From these records alone, the orthodontist was able to perform a type of triage (i.e., determine whether the one-step diagnosis and treatment-planning approach would be appropriate or whether additional records and multistep treatment planning would be needed). A brief review of the photographs and panoramic radiograph allowed the orthodontist to make the four major treatment-planning decisions in orthodontics, which in turn determine the number of visits required for a complete diagnosis and treatment plan:

1. Extraction versus nonextraction: A.S.'s crowding and overjet were insufficient to warrant premolar extractions.
2. Conventional anchorage versus skeletal anchorage: None of the characteristics of A.S.'s orthodontic condition required skeletal anchorage for their correction.
3. Surgical orthodontics versus nonsurgical treatment: A.S.'s facial appearance did not indicate a need for dramatic changes in her skeletal relationships.
4. Interdisciplinary or multidisciplinary treatment: A.S.'s excellent overall oral health obviated the need for the participation of any other dental specialists in her treatment.

Clinical Examination

The clinical examination revealed the following:

1. Dentofacial appearance
   - Decreased maxillary incisor display
   - Normal orientation of the esthetic line of the dentition
   - Convex, posteriorly divergent profile resulting primarily from mandibular retrognathism
   - Retrusive lips with thin upper lip vermillion
   - Deep mentolabial fold with a strong pogonial projection
2. Alignment, arch form, and symmetry
   - A 4-mm maxillary arch perimeter deficiency, 3-mm mandibular arch perimeter deficiency
   - Elliptical maxillary and mandibular arch form with slight asymmetry of the maxillary anterior segment
3. Transverse relationships
   - Average width and height of the palatal vault
   - A 2-mm maxillary transverse deficiency at the level of the first and second molars without posterior crossbite
   - Maxillary posterior dental compensation for the Class II relationship (crowns tipped palatally)
4. Anteroposterior relationships
   - Class II, division 1 with 4-mm overjet
   - Maxillary anterior dental compensation (retroinclination of maxillary incisors) through crowding of maxillary anterior teeth
5. Vertical relationships
   - Anterior deep bite (60% overbite)

Prioritized Problem List

- Crowding
- Class II molar relationship, excessive overjet, profile concerns
- Slightly insufficient anterior tooth display
- Anterior deep bite
- Slightly narrow maxillary dental arch

Potential Solutions to the Individual Problems

- Crowding—Lateral and anterior expansion of 2 mm
- Class II—Restrain maxillary forward growth, distalize maxillary molars, slightly procline mandibular teeth
- Overjet—Attempt to redirect facial growth; retract maxillary teeth
- Decreased maxillary incisor display—Attempt to enhance eruption of maxillary anterior teeth
- Anterior deep bite—Differential eruption (i.e., enhance eruption of posterior teeth while inhibiting eruption of mandibular anterior teeth)
- Slightly narrow maxillary dental arch—Expand maxillary dental arch

Interactions and Risk/Benefit Considerations of Potential Solutions

- The interactions of the potential solutions to the prioritized problems are all favorable (i.e., no tentative solution to one problem unfavorably impacts the tentative solution to another problem).
- The risk of dental expansion is that it might ultimately lead to instability.

Unified Treatment Plan

- Relieve the crowding with dental expansion.
- Place posteriorly and superiorly directed traction on the maxillary molars and anteriorly directed traction on the mandibular arch.
- Place extrusive force on maxillary anterior teeth and intrusive force on mandibular anterior teeth.

Mechanotherapy

Alternatives

- Fixed appliances with high pull headgear and Class II elastics *or*
- A combination of fixed and functional appliances or a fixed functional appliance. (Although the skeletal maturation according to the Cervical Vertebral Maturation Index[100] would suggest minimal remaining growth, the dental effect from a fixed functional appliance [Herbst], including mandibular incisor proclination and intrusion, were favorable in correcting multiple items on the problem list).
- A maxillary Hawley retainer and a bonded mandibular canine-to-canine fixed retainer
- *At this point in the process, the orthodontist turns over the following tasks to the Treatment Coordinator.*

Continued

CASE STUDY 1-1 A PATIENT WITH AN ORTHODONTIC CONDITION AMENABLE TO THE ONE-STEP DIAGNOSIS AND TREATMENT-PLANNING APPROACH—cont'd

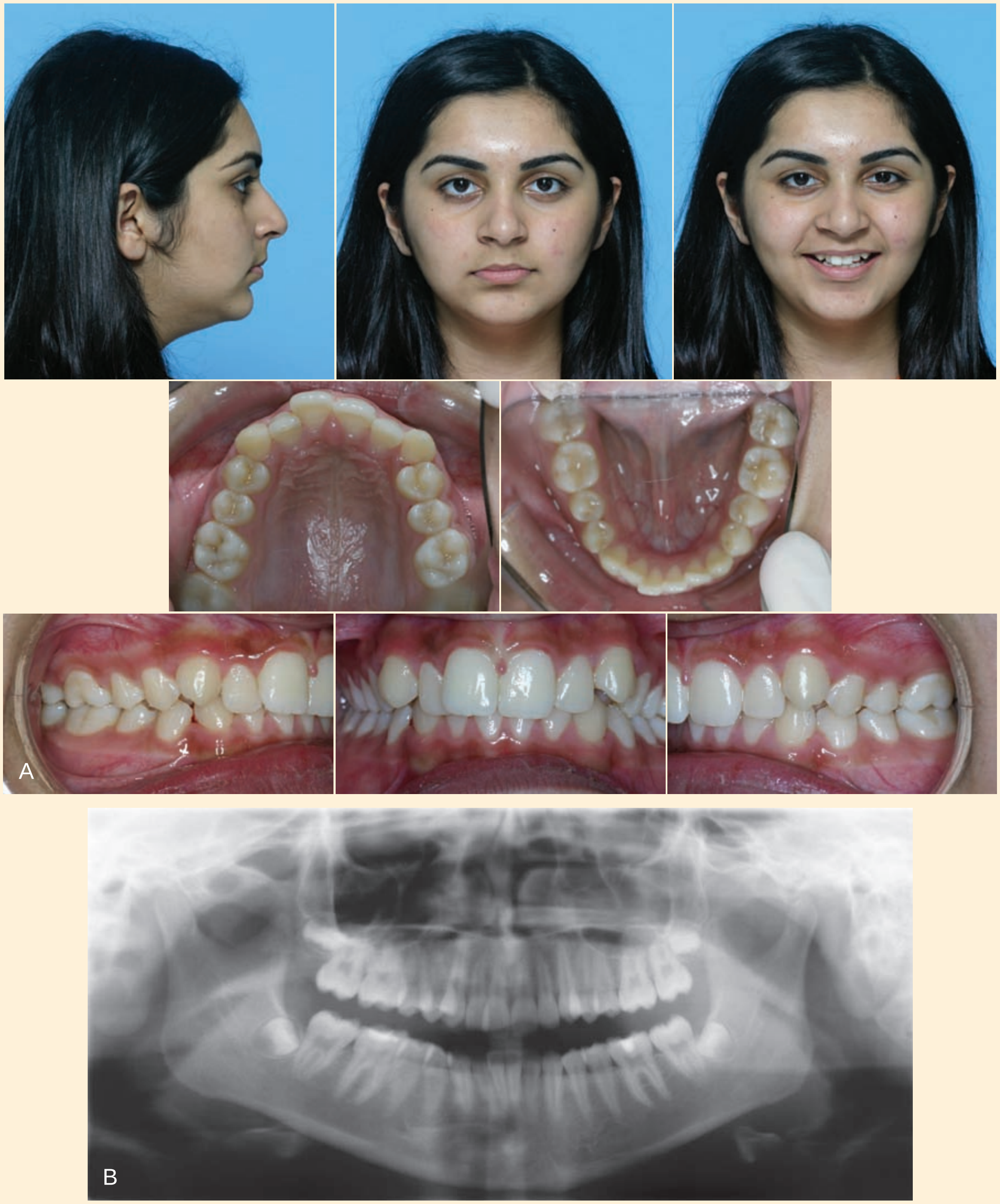


FIGURE 1-27 **A,** Pretreatment photographs. **B,** Pretreatment panoramic radiograph. **C,** Pretreatment cephalogram. **D,** Post-treatment photographs. **E,** Cephalometric superimpositions.

Patient/Parent Input

Given the two alternatives, the family expressed a preference for a noncompliance approach and was shown a Herbst appliance. The joint decision was made to use a combination of fixed and fixed functional appliances.

Informed Consent

A modification of the AAO informed consent booklet was used to outline the risk/benefit considerations of treatment including retention considerations. The estimate of treatment time and the cost of treatment were discussed.

CASE STUDY 1-1 **A PATIENT WITH AN ORTHODONTIC CONDITION AMENABLE TO THE ONE-STEP DIAGNOSIS AND TREATMENT-PLANNING APPROACH—cont'd**

Supplemental Records

A lateral cephalogram and dental impressions were taken to confirm the findings from the clinical examination (Figure 1-27, *C*).

Detailed Treatment Plan

At a later date, the supplemental records were reviewed and the prioritized problem list, detailed treatment plan, and stepwise outline of the mechanotherapy were recorded and placed in a readily accessible part of the patient's file.

Post-treatment Evaluation

The outcome of treatment is shown in Figure 1-27, *D* and *E.*

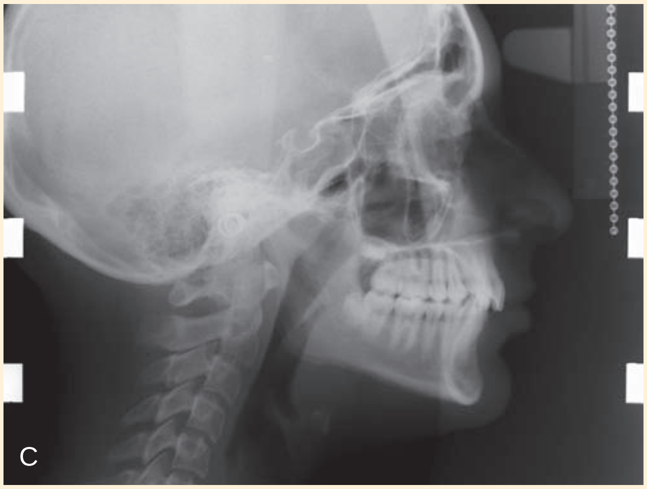


FIGURE 1-27C

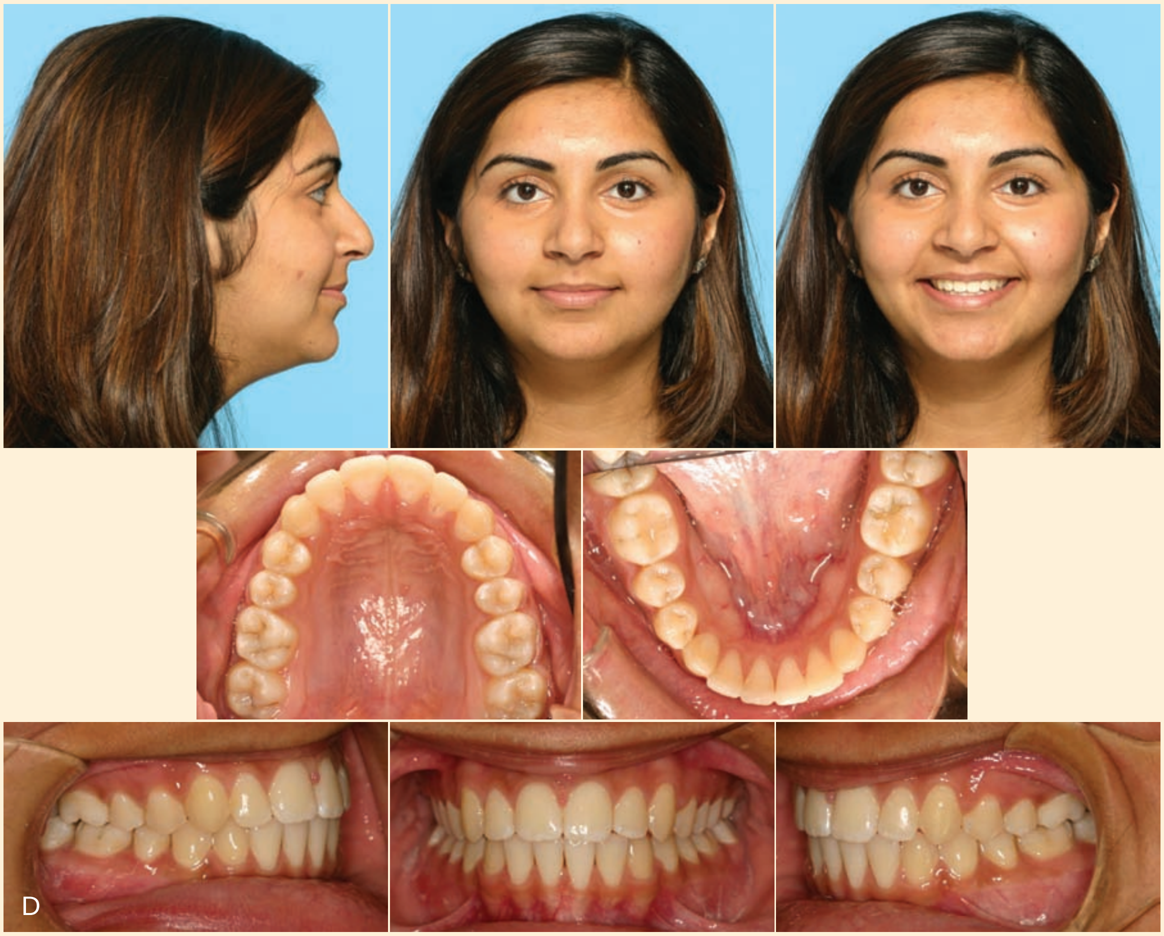


FIGURE 1-27, D

Continued

CASE STUDY 1-1 A PATIENT WITH AN ORTHODONTIC CONDITION AMENABLE TO THE ONE-STEP DIAGNOSIS AND TREATMENT-PLANNING APPROACH—cont'd

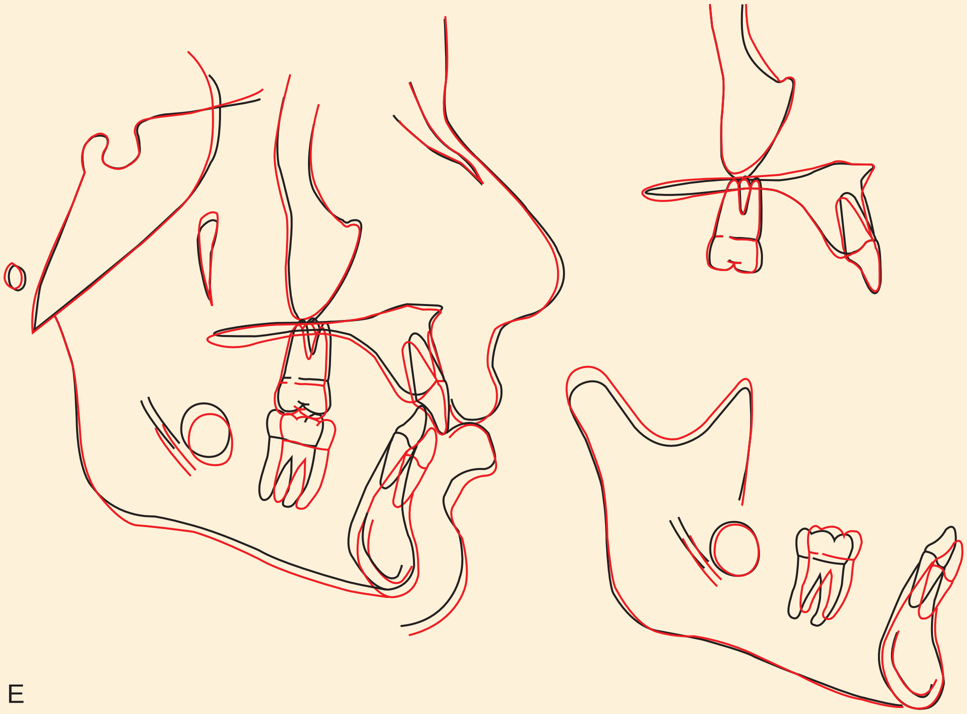


FIGURE 1-27, E

CASE STUDY 1-2 A PATIENT WITH AN ORTHODONTIC CONDITION REQUIRING A MULTIPLE-STEP DIAGNOSIS AND TREATMENT-PLANNING APPROACH

This patient required another appointment for supplemental records including special imaging for diagnostic and treatment planning purposes. After processing of the additional data, the patient and parent required an additional meeting with the orthodontist to discuss the treatment alternatives. The patient/parent and the orthodontist at this conference jointly constructed a treatment decision. With a complex treatment-planning problem for a patient and family who has had no previous experience with orthodontics, it is not feasible to use the one-step treatment-planning process. Although this patient was treated in a university setting, the case report will be written as if she had been seen in private practice.

Patient History

Patient A.D., a healthy, well-nourished, physically mature and socially well-adjusted 14-year-old North American white girl presented for an orthodontic evaluation with a chief complaint of "a space between my upper front teeth" and "the next tooth over is in toward the roof of my mouth" (which was interpreted to mean a palatally displaced lateral incisor). None of her parents or siblings had yet had orthodontic treatment, although A.D. and her brother had been evaluated by two other orthodontists.

Initial Records

Photographs and a panoramic radiograph were obtained by the treatment coordinator before the clinical examination by the orthodontist (Figure 1-28, *A, B*).

Triage

A brief review of the photographs and panoramic radiograph allowed the orthodontist to make the following critical preliminary judgments:

1. A.D.'s crowding, although the maxillary right lateral incisor was largely blocked out of the arch, was insufficient to warrant tooth extractions.
2. Several of the characteristics of A.D.'s orthodontic condition possibly required either orthognathic surgery or skeletal anchorage to completely resolve the problems.

Clinical Examination

The clinical examination revealed the following:

1. Dentofacial Appearance
    - Dolichofacial appearance with long lower face height
    - Excessive posterior gingival show
    - Downward posterior cant (pitch) of the esthetic line of the dentition
    - Mild dental cant (roll) of the anterior teeth slightly up on the patient's right side
    - Maxillary midline shifted 2 mm to the right side
    - Concave, straight profile with retrusive lips and thin upper lip vermillion
    - Obtuse nasolabial angle
    - Effaced mentolabial fold

CASE STUDY 1-2 A PATIENT WITH AN ORTHODONTIC CONDITION REQUIRING A MULTIPLE-STEP DIAGNOSIS AND TREATMENT-PLANNING APPROACH—cont'd

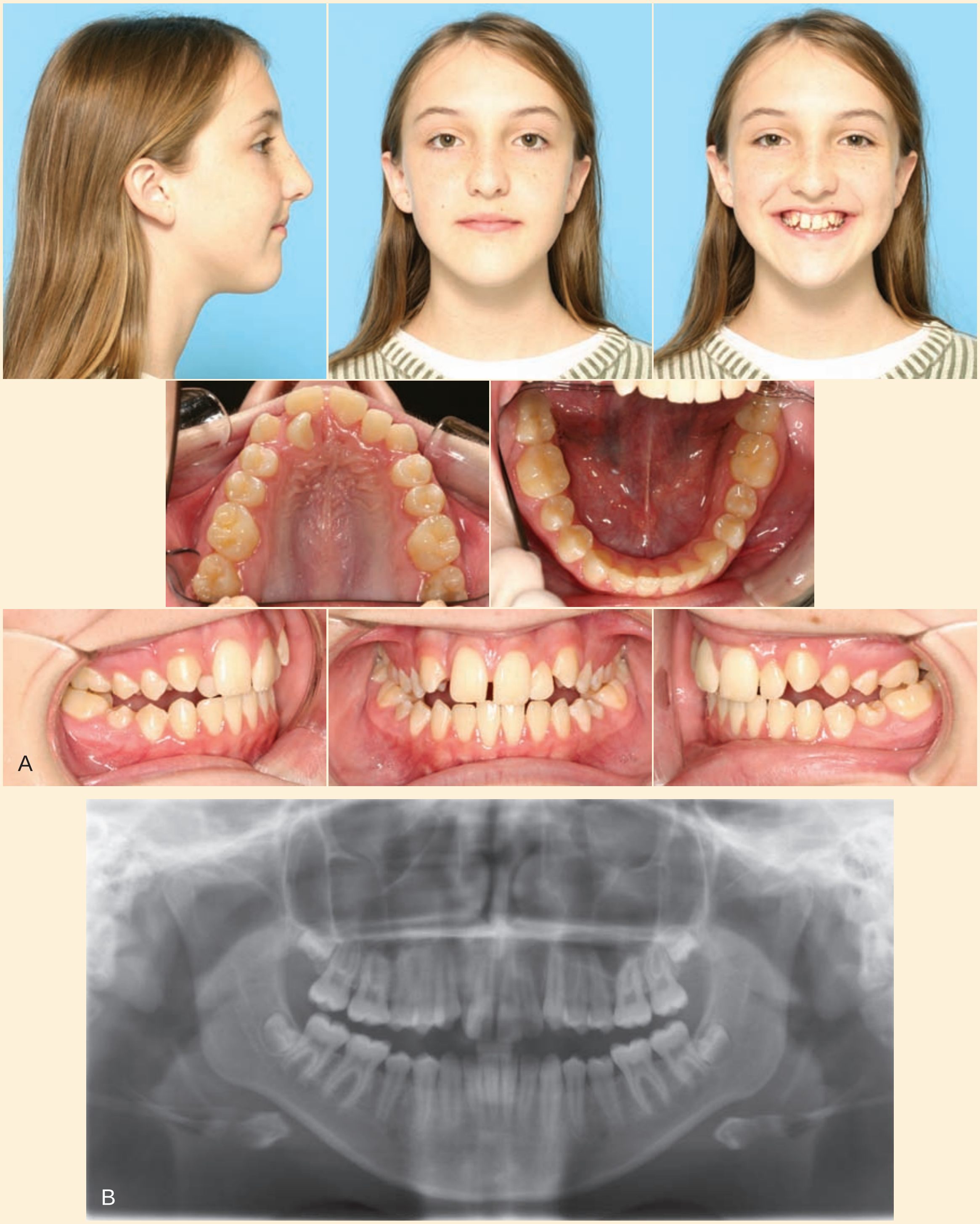


FIGURE 1-28 **A,** Pretreatment photographs. **B,** Pretreatment panoramic radiograph. **C,** Pretreatment cephalogram. **D,** Video imaging predictions. **E,** Post-treatment photographs. **F,** Cephalometric superimpositions.

2. Alignment, Symmetry and Arch Form
   - "V-shaped" maxillary arch and "U-shaped" mandibular arch
   - A 4-mm maxillary arch perimeter deficiency in the region of the blocked out maxillary right lateral incisor, albeit there is a 1-mm maxillary midline diastema
   - Maxillary midline is shifted 2 mm to the patient's right.
   - Tooth size discrepancy due to the maxillary right lateral incisor
   - Maxillary right permanent first molar is rotated mesially, contributing to the arch perimeter deficiency affecting the maxillary right lateral incisor.
   - Maxillary canines in slight labial ectopic position

Continued

CASE STUDY 1-2 A PATIENT WITH AN ORTHODONTIC CONDITION REQUIRING A MULTIPLE-STEP DIAGNOSIS AND TREATMENT-PLANNING APPROACH—cont'd

3. Transverse Relationships
   - High constricted palatal vault
   - A 7-mm maxillary transverse deficiency at the level of the first and second molars
   - Bilateral maxillary palatal crossbite
4. Anteroposterior Relationships
   - Class II, with 4-mm overjet and palatal crossbite the maxillary right lateral incisor
5. Vertical Relationships
   - Lateral open bites in the canine and premolar regions on the right and left side
   - Anterior open bite tendency
   - Only three points of occlusal contact—maxillary and mandibular second molars and the maxillary right lateral incisor

Prioritized Problem List

- Maxillary midline diastema
- Palatoversion of the maxillary right lateral incisor
- Unesthetic anterior tooth display
- Bilateral maxillary palatal crossbites
- Lateral open bites
- Anterior open bite tendency
- Increased lower face height

Potential Solutions to the Individual Problems

- Maxillary midline diastema—After maxillary expansion, redistribute maxillary anterior space to close the diastema
- Palatoversion of the maxillary right lateral incisor—After posterior expansion and redistribution of maxillary anterior spacing, level and align lateral incisor
- Unesthetic anterior tooth display—If possible, intrude maxillary posterior teeth and change orientation of the esthetic line of the dentition, level and align teeth
- Bilateral maxillary palatal crossbites—Rapid palatal expansion (10 mm)
- Lateral open bites—Either extrusive forces on the maxillary canines and premolars or intrusive forces on the molars
- Anterior open bite tendency—Intrusion of maxillary molars and autorotation of the mandible or extrusion of mandibular incisors
- Increased lower face height—Intrude maxillary posterior teeth or consider a LeFort I osteotomy to superiorly reposition the maxillae and gain autorotation of the mandible

Interactions and Risk/Benefit Considerations of Potential Solutions

- Expanding the maxillary arch has the potential for increasing face height, which is already long, particularly since the maxillary molars manifest buccal crown inclination.
- Maxillary expansion can increase the open bite tendency by tipping the maxillary molars, effectively bringing the palatal cusps inferiorly.
- The risk of maxillary expansion is that it might ultimately lead to instability of the maxillary dental arch.

Treatment Possibilities

Alternatives

1. Rapid palatal expansion to correct posterior crossbites and skeletal anchorage to control the vertical dimension, particularly posteriorly
2. Surgical correction of the posterior crossbites and open bites using a LeFort I maxillary osteotomy

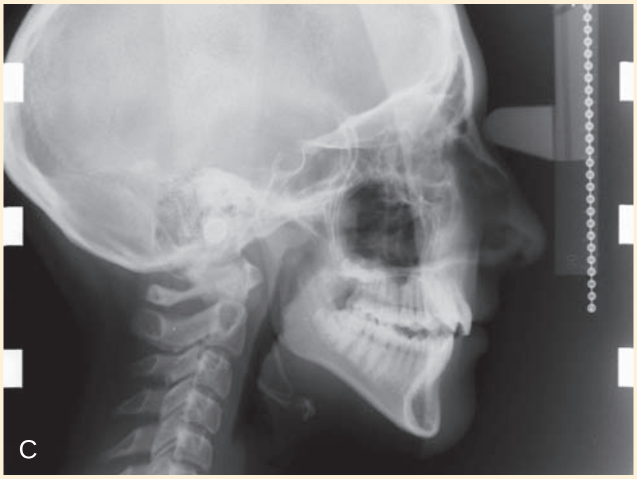


FIGURE 1-28, C

Supplemental Records

- A lateral cephalogram and dental impressions were taken for further study. Video imaging simulated the potential facial outcomes that might result from orthodontics plus surgery (Figure 1-28, *C*).

Patient/Parent Conference

All records were reviewed with the patient and parent. The family was told the treatment alternatives and was shown bone anchors, a rapid palatal expansion appliance, and multibonded appliances, as well as simulations of orthognathic surgical technique and the potential changes that might be derived from surgery in this case.

Given the two treatment alternatives, the family expressed a strong preference for the less invasive treatment plan despite the fact that a more optimal facial outcome might have resulted from orthognathic surgery (Figure 1-28, *D*).

Unified Treatment Plan

- Relieve crowding of the maxillary right lateral incisor with 10 mm of rapid palatal expansion and correct posterior crossbites
- Intrude maxillary posterior teeth with the aid of skeletal anchorage
- Improve appearance of anterior tooth display with multibonded appliances

Informed Consent

A modification of the AAO informed consent booklet was used to outline the risk/benefit considerations of treatment including retention considerations. The 2-year estimate of treatment time and the cost of treatment were discussed.

Detailed Treatment Plan and Mechanotherapy

1. After the conference, the prioritized problem list, detailed treatment plan, and stepwise outline of the mechanotherapy were recorded and placed in a readily accessible part of the patient's file. The plan was similar to one of the original treatment alternatives (i.e., rapid palatal expansion to correct posterior crossbites, skeletal anchorage to control the vertical dimension, particularly posteriorly and fixed appliances).

Post-treatment Evaluation

The outcome of treatment is shown in Figure 1-28, *E, F*.

CASE STUDY 1-2 **A PATIENT WITH AN ORTHODONTIC CONDITION REQUIRING A MULTIPLE-STEP DIAGNOSIS AND TREATMENT-PLANNING APPROACH—cont'd**

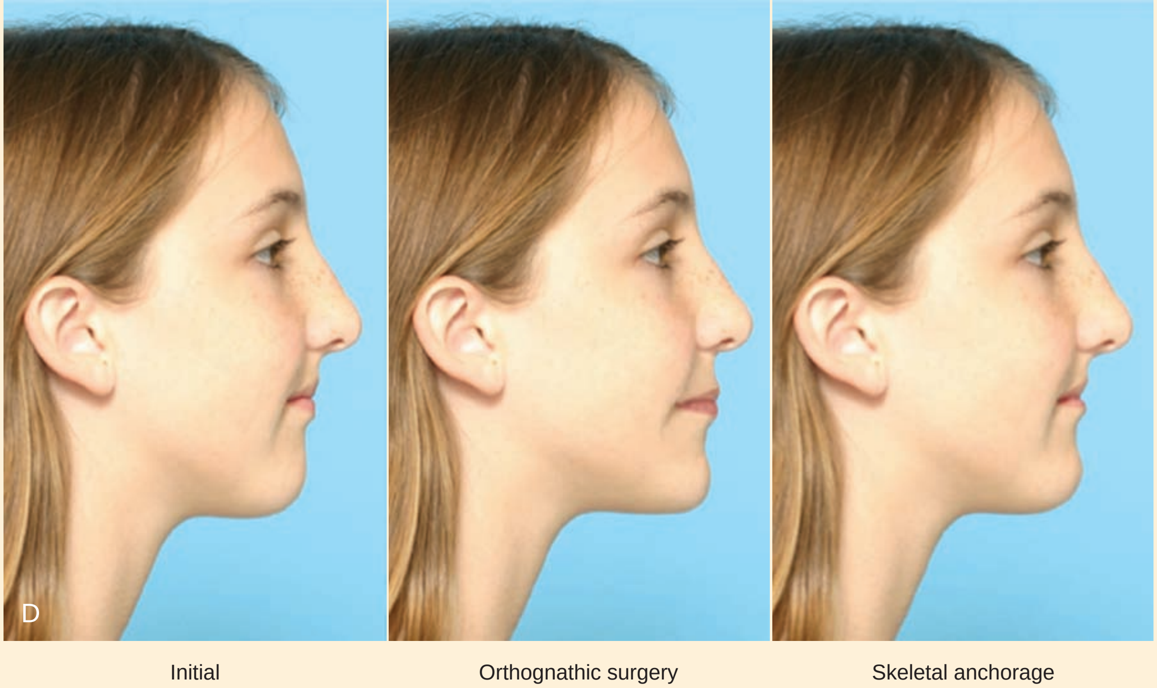


FIGURE 1-28, D

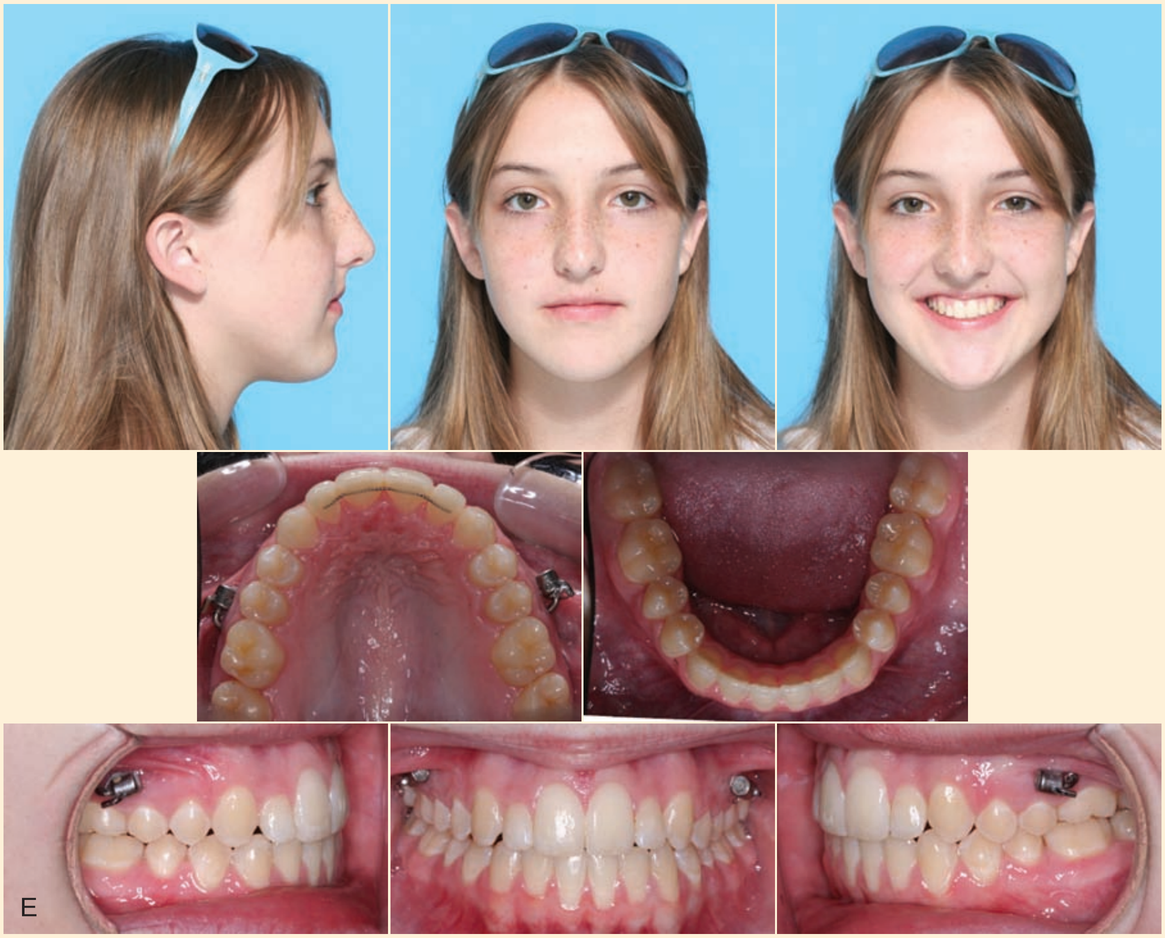


FIGURE 1-28, E

Continued

CASE STUDY 1-2 **A PATIENT WITH AN ORTHODONTIC CONDITION REQUIRING A MULTIPLE-STEP DIAGNOSIS AND TREATMENT-PLANNING APPROACH—cont'd**

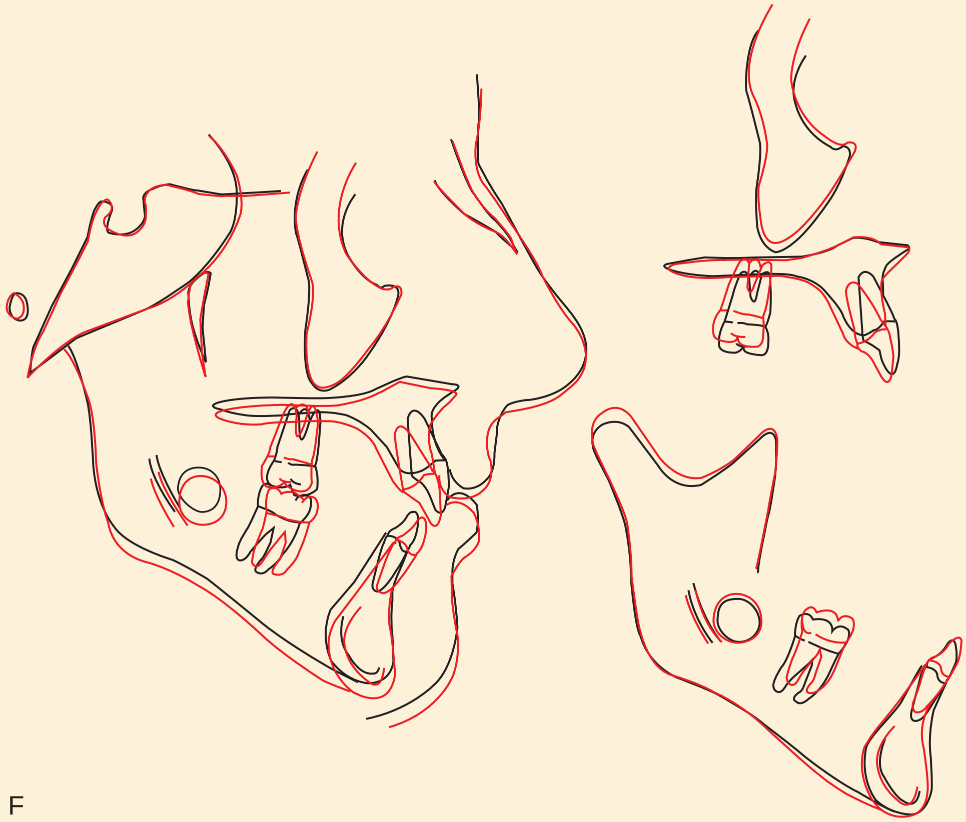


FIGURE 1-28, F

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CHAPTER 2

Special Considerations in Diagnosis and Treatment Planning

David M. Sarver, Mark Yanosky

OUTLINE

Purposes and Goals of Orthodontic Treatment
  Orthodontics and Quality of Life
  Role of the Orthodontist in Total Facial Aesthetic Planning
  Records
    Facial Photographs
    Digital Video Technology in Orthodontic Records
    Intraoral Photographs
    Cephalometric Radiographs
    Contemporary Applications of Cephalometry
    Computer Imaging in Contemporary Treatment Planning
Clinical Examination of Facial Symmetry and Proportion: Its Significance in Treatment Planning
  Application of Database Programs to Clinical Information
Frontal Vertical Facial Relationships
  Increased Face Height
  Decreased Face Height
Transverse Facial and Dental Proportions
  Central Fifth of the Face
  Medial Two Fifths of the Face
  Outer Two Fifths of the Face
Evaluation of Nasal Proportions
  Radix
  Nasal Dorsum
  Nasal Tip
  Columella
  Nasolabial Angle
Lip Projection
  Excessive versus Inadequate Lip Projection
  Effects on the Labiomental Sulcus
Chin Projection
Throat Form
Evaluation of the Smile (Miniesthetics)
  Importance of the Smile in Orthodontics
  Analysis of the Smile
  Diagnostic Smile Analysis: Measurement of Characteristics
  Vertical Characteristics of the Smile
  Transverse Characteristics of the Smile
Oblique Characteristics of the Smile
Dental Microesthetics and Its Applications to the Smile
  Gingival Shape and Contour
  Bracket Placement in Preparation for Changes in Gingival Shape
  Bracket Positioning for Optimal Aesthetics

Orthodontic diagnosis and treatment planning are in a period of remarkable change, away from a previous focus on dental occlusion and hard tissue relationships and toward a greater emphasis on soft tissue adaptation and proportions.[1,2] Dentists have become more aware of the developments in cosmetic dentistry and the benefits now available to their patients. Parents and patients now notice and disapprove of the aesthetic liability of unattractive smiles and as a result, orthodontists know that treatment success must be judged by more than the dental occlusion. Chapter 1 of this book has cogently discussed the current philosophical changes in the approach to diagnosis and treatment planning, departing from the traditional model consisting of an initial visit followed by records and subsequent analysis and treatment plan presentation. Until the past decade, the emphasis in planning orthodontic treatment was based on photographs, model analysis, and cephalometric analysis. The contemporary approach involves a much more detailed clinical examination where many aspects of the treatment plan reveal themselves as a function of the systematic evaluation of the functional and aesthetic presentation of the patient. Because Chapter 1 also covered the functional aspects of orthodontic treatment, our intent in this chapter is to present the components of clinical assessment of the hard tissue and soft tissue that logically leads the clinician to the final treatment plan. In planning treatment, to visualize and establish the appearance of the teeth and face that is desired as a treatment outcome and to work backward ("retro

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engineer") to the hard tissue relationships that are needed to obtain these soft tissue proportions and lip–tooth relationships makes much more sense. This approach is not totally contradictory to the records-based approach, where the hard tissues are analyzed (cephalometric head film and models) and the outward soft tissue is a secondary consideration, but should be considered an expansion of how we diagnose and treatment plan. It is important, however, that in many instances, the clinical observations should override the cephalometric impression.

The purpose of this chapter is to explore in detail the new concepts that underlie clinical application of the soft tissue paradigm with the major emphasis on appearance and aesthetics. The next objective will be to illustrate how treatment approaches change when these concepts are applied. The focus is on the things that have not been emphasized in previous discussions of orthodontic diagnosis and treatment planning. The authors know that the reader will have a background in those fundamentals, because Chapter 1 covers that in exquisite detail.

PURPOSES AND GOALS OF ORTHODONTIC TREATMENT

Orthodontics and Quality of Life

In general, the goal of orthodontic treatment is to improve the patient's life by enhancing dental and jaw function and dentofacial aesthetics. From this perspective, the role of orthodontics is analogous to that of several other medical specialties, such as orthopedics and plastic surgery, in which the patient's problems often do not result from disease but rather from distortions of development. As the health care has evolved from a disease-oriented focus to a wellness model,[3] orthodontics now is viewed more clearly as a health service dedicated to establishing emotional and physical wellness. Dental and facial distortions create a disability that can influence physical and mental health. Appropriate treatment can be important for the patient's well-being.

In diagnosis, whether in orthodontics or other areas of medicine or dentistry, practitioners must not concentrate so closely on their own specialized areas (and a medical or dental professional does not have to be a specialist to take a specialized point of view) when assessing patients' overall conditions that they overlook other significant problems. The problem-oriented approach to diagnosis and treatment planning has been advocated widely in medicine and dentistry as a way to overcome this tendency to concentrate on only one part of a patient's problem. The essence of the problem-oriented approach is the development of a comprehensive database of pertinent information that precludes the possibility of problems being overlooked. We suggest that the problem-oriented treatment-planning approach has grown further to include examination, documentation, and assessment of patient attributes that are normal or positive attributes. The reason for this is the recognition that in orthodontic treatment, we may often have an unwittingly negative impact on patient attributes that are good.[4–6] The most commonly cited example of this is the case in which correction of a Class II malocclusion secondary to mandibular deficiency is performed via maxillary first premolar extraction and reduction of overjet. This plan corrects the Class II problem but at the expense of a normal or ideal midface.

Chapter 1 gives the reader a basic understanding of the problem-oriented approach to orthodontic diagnosis and treatment planning and of dental cast and cephalometric analysis, so the focus of this chapter is on soft tissue considerations that previously have not received as much consideration in orthodontic evaluation as they should have and on the integration of traditional orthodontic treatment procedures with other treatment (periodontal, restorative, surgical) that can improve the outcome for many patients.

Role of the Orthodontist in Total Facial Esthetic Planning

One of the first major influences in changing orthodontic thinking and approach began when orthognathic surgery became a more refined and less traumatic procedure; it rapidly became a reasonable treatment option for orthodontists to incorporate into their differential diagnoses and treatment planning strategies. The facial changes created by improvement of skeletal malformations were truly remarkable, and the facial effect of orthognathic treatment moved to the forefront of orthognathic surgical goal setting.

The retreatment of orthodontically camouflaged cases and the recognition of the effect of orthodontics and growth modification on the face have changed the focus of "routine" orthodontic treatment. The goals of orthognathic treatment for the improvement of facial appearance may be attained readily by orthodontic methods in children, but the tools are different for different ages: orthognathic surgery in the adult for skeletal modification and growth modification in the adolescent.

The aesthetic and functional goals for growing patients should be the same as they are for adult patients. Growth modification techniques may allow the orthodontist to direct growth to achieve dramatic facial changes similar to those produced by surgery; these changes are an important part of patient motivation and satisfaction. Individualized treatment plans with differential functional and aesthetic options of treatment should be planned and discussed with the parents of young patients. Adult patients tend to choose more aggressive approaches to treatment, whereas the parents of adolescent patients are more cautious. This occurs probably for two reasons: (1) the parents are making decisions on behalf of the child and tend to be more conservative, whereas the adult is making personal treatment decisions; and (2) some surgical decisions are not needed or indicated during adolescence.

Before cephalometric radiography, astute clinicians looked at the face and made general correlations with the way tooth movement might affect the esthetics of the face. Cephalometrics quantified dentoskeletal relations, established norms, and focused the profession on anatomic relations including the skeletal pattern. Cephalometric diagnostic guidelines, however, pay only marginal attention to the soft tissue profile, although many analyses include soft tissue characteristics. The emphasis on cephalometrics that developed in clinical orthodontic diagnosis and treatment planning departed from the original vision of its developers. Brodie[7] cautioned that cephalometrics was never intended as the sole decision maker in orthodontic treatment plans and that its main strength was in quantification of growth and research.

Interestingly, orthodontics is now coming full circle, looking carefully at dentofacial proportions before the cephalometric radiograph is even considered. Of even greater significance is the modern emphasis on the frontal evaluation and the effect of orthodontics and surgery on the frontal vertical relationships.

The greater recognition of facial planning is only one leg of the contemporary diagnostic tripod. We recommend that aesthetic planning be approached with three major divisions in mind—macroesthetics (the face), miniesthetics (the smile), and microesthetics (tooth and gingival shape and form. (To see case studies demonstrating this approach, please go to www.orthodontics-principles-techniques.com.) Contemporary records should reflect this approach and facilitate the complete three-dimensional evaluation of the patient's aesthetic presentation.

Records

Facial Photographs. For ideal photographic representation of the face, the authors recommend that the camera be positioned in the "portrait" position to maximize use of the photographic field. Orienting the camera in "landscape" position captures much of the background that is unneeded and detracts from the image by diminishing the size of the face in the picture.

The following facial photographs are recommended as the expected routine for each patient:

1. *Frontal:* The patient assumes a natural head position and looks straight ahead into the camera. Four types of frontal photographs (Figure 2-1) are useful:
    a. *Frontal at rest.* If lip incompetence is present, the lips should be in repose and the mandible in rest position.
    b. *Frontal view with the teeth in maximal intercuspation, with the lips closed, even if this strains the patient.* This photograph serves as clear documentation of lip strain and its aesthetic effect, and the lips-together picture is recommended in patients who have lip incompetence. If lips-apart posture is present, then an unstrained image is also recommended. The reason for this image is to allow visualization of the philtrum–commissure height relationship, etiologic in the differential diagnosis of excessive gingival display on smile.
    c. *Frontal dynamic (smile).* As described in more detail later in this chapter, the smile can vary with emotion. A patient who is smiling for a photograph tends not to elevate the lip as extensively as a laughing patient. The smiling picture demonstrates the amount of incisor show on smile (percentage of maxillary incisor display on smile) and any excessive gingival display. The still image of the smile can be variable. Think about it—we squeeze off a picture that is about $\frac{1}{125}$-second duration in a process that has a start and a finish (from the lips together through the smile animation back to the lips being together). Also, having a child relax during the photograph session can also be a challenge. Many times we can only obtain a forced smile at best. Because of this variability, we recommend the addition of digital video clips as part of the patient record.[6,7] This will be discussed in detail later in this section.
    d. *A close-up image of the posed smile.* This view now is recommended as a standard photograph for careful analysis of the smile relationships. The posed smile photograph is discussed in greater detail later in the chapter.
2. *Oblique (three-quarter, 45-degree):*
   Patient in natural head position looking 45 degrees to the camera. Three views are useful (Figure 2-2).
    a. *Oblique at rest.* This view is useful for examination of the midface and is particularly informative of midface deformities, including nasal deformity. Orthodontists should recognize that persons are not seen just on profile or frontally and that the three-quarter view is particularly valuable in assessing the way a patient's face is viewed by others. This view also reveals anatomic characteristics that are difficult to quantify but are important aesthetic factors, such as the chin-neck area, the prominence of the gonial angle, and the length and definition of the border of the mandible. The view also permits focus on lip fullness and vermilion display. For a patient with obvious facial asymmetry, oblique views of both sides are recommended.
    b. *Oblique on smile.* As mentioned in Chapter 1, there are diagnostic limitations of plaster casts, virtual models, and, as far as we are concerned, virtually all static records because they do not reflect the relationships of the teeth to the lips and surrounding soft tissue, especially in evaluation of

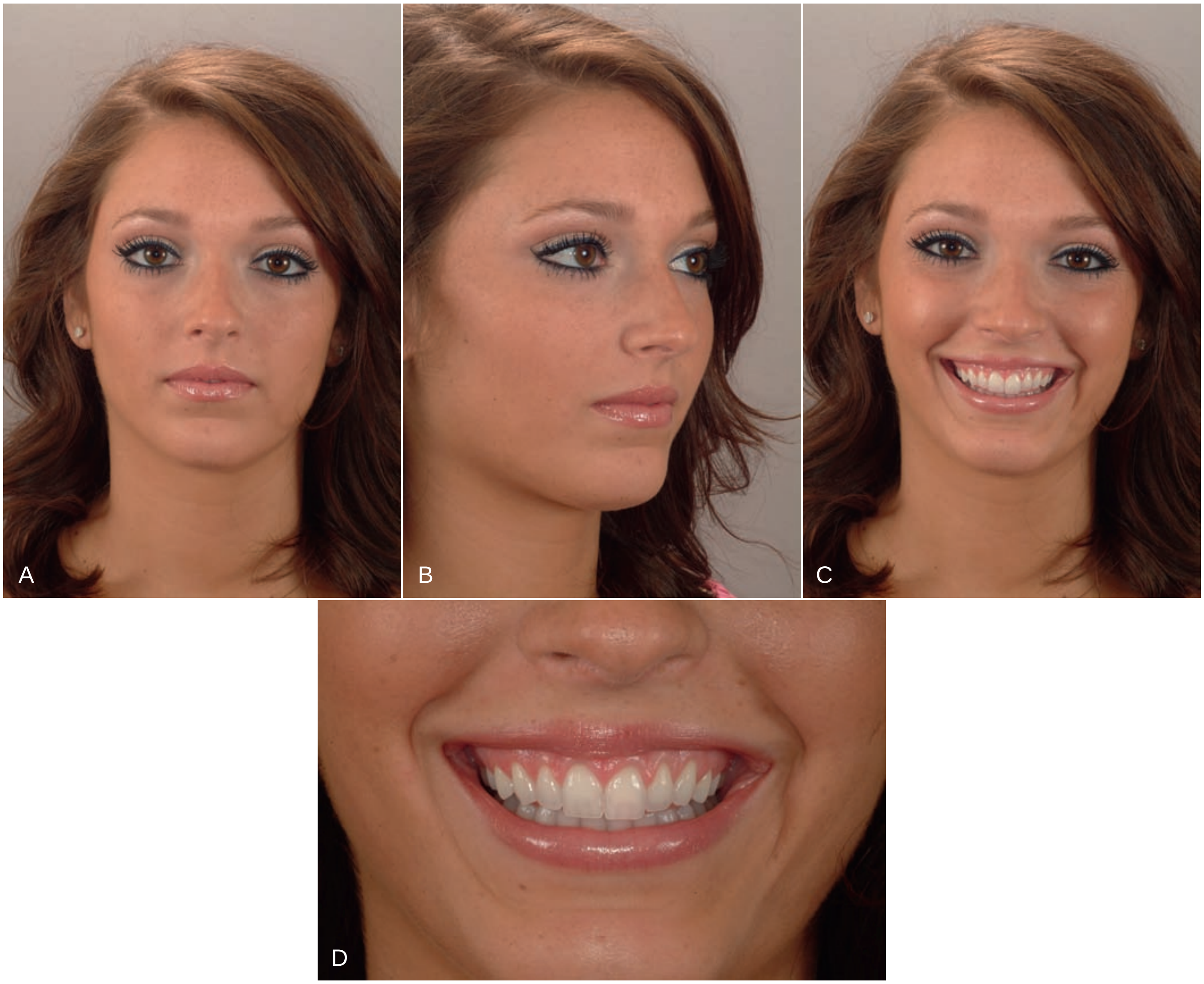


FIGURE 2-1 Recommended frontal images. **A,** Frontal at rest. If lip incompetence is present, the lips should be in repose and the mandible in rest position. **B,** Frontal view with the teeth in maximal intercuspation, with the lips closed, even if this strains the patient. This photograph serves as clear documentation of lip strain and its esthetic effect, and the lips-together picture is recommended in patients who have lip incompetence. **C,** Frontal dynamic (smile). A patient who is smiling for a photograph tends not to elevate the lip as extensively as a laughing patient. The smiling picture demonstrates the amount of incisor show on smile (percentage of maxillary incisor display on smile), as well as any excessive gingival display. **D,** A close-up image of the posed smile. This is now recommended as a standard photograph for careful analysis of the smile relationships.

the smile. Standard orthodontic records consist of the frontal smile, frontal rest, and profile. Often, in clinical practice, a parent will ask why the teeth appear flared, and they do a credible job of illustrating what they are seeing by holding their hands next to the child's face to make sure the orthodontist sees it, too. This observation is often not discernible on the models or on the cephalogram but is readily observable on the patient. So the oblique view of the smile reveals characteristics of the smile not obtainable through those means and it aids the visualization of both incisor flare and occlusal plane orientation. A particular point for observation is the anteroposterior cant of the occlusal plane. In the most desirable orientation, the occlusal plane is consonant with the curvature of the lower lip on smile (the smile arc, discussed in detail in the section on smile evaluation). Deviations from this orientation that should be noted as potential problems include a downward cant of the posterior maxilla, an upward cant of the anterior maxilla, or variations of both. In the initial examination and diagnostic phase of treatment, visualization of the occlusal plane in its relationship to the upper and the lower lip is important.

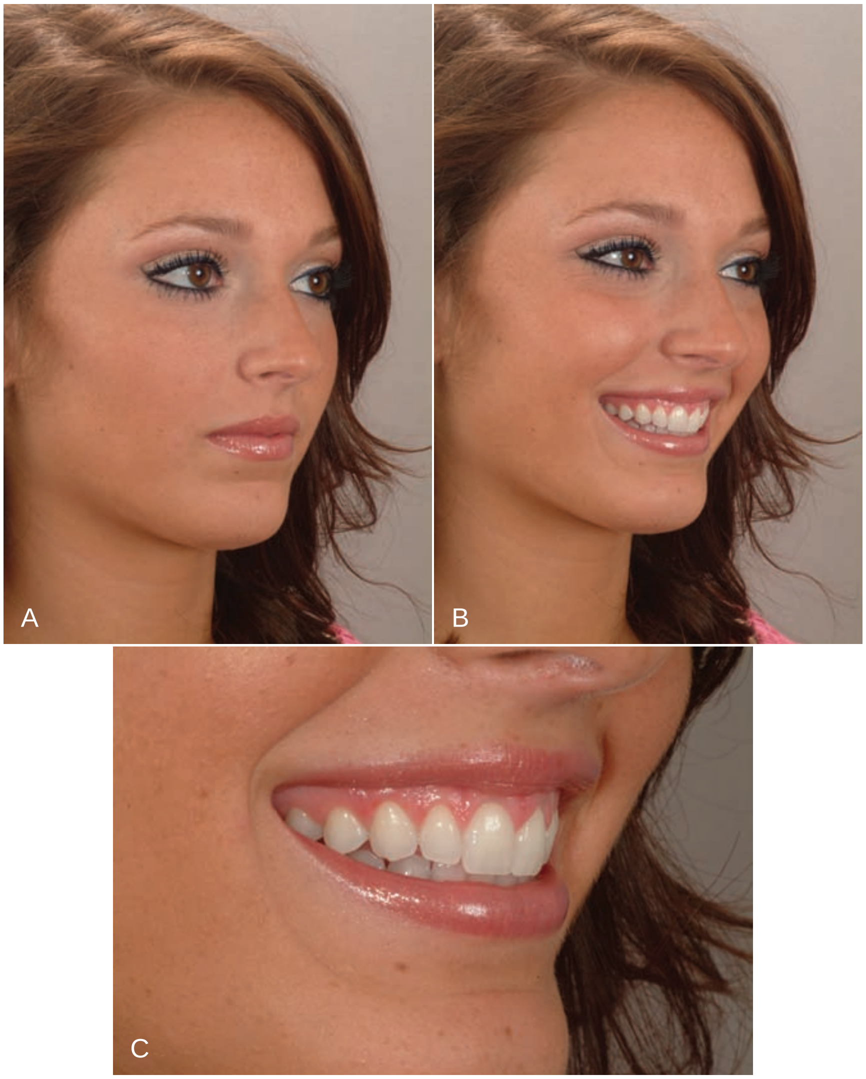


FIGURE 2-2 Oblique (three-quarter, 45-degree) views. Three views are useful. **A,** Oblique at rest. This view can be useful for examination of the midface and is particularly informative of midface deformities, including nasal deformity. This view also reveals anatomic characteristics that are difficult to quantify but are important aesthetic factors, such as the chin-neck area, the prominence of the gonial angle, and the length and definition of the border of the mandible. This view also permits focus on lip fullness and vermilion display. **B,** Oblique on smile. The oblique view of the smile reveals characteristics of the smile not obtainable on the frontal view and certainly not obtainable through any cephalometric analysis. **C,** Oblique close-up smile. This view allows a more precise evaluation of the lip relationships to the teeth and jaws than is possible using the full oblique view.

   c. *Oblique close-up smile*. This allows a more precise evaluation of the lip relationships to the teeth and jaws than is possible using the full oblique view.

      Figure 2-3 illustrates the close-up smiles on the oblique view of a child presenting for correction of an open bite and his mother.

3. *Profile* (Figure 2-4): The profile photographs also should be taken in a natural head position. The most common method used for positioning the patient properly is to have the patient look in a mirror, orienting the head on the visual axis. The picture boundaries should emphasize the areas of information needed for documentation and diagnosis. The authors recommend that the inferior border be slightly above the scapula, at the base of the neck. This position permits visualization of the contours of the chin and neck area. The superior border should be only slightly above the top of the head, and the right border slightly ahead of the nasal tip.

   The inclusion of more background simply adds unneeded information to the photograph. Some clinicians prefer that the left border stop just behind the ear, whereas others prefer a full head shot. Under any circumstance, the hair should be pulled behind the ear to permit visualization of the entire face.

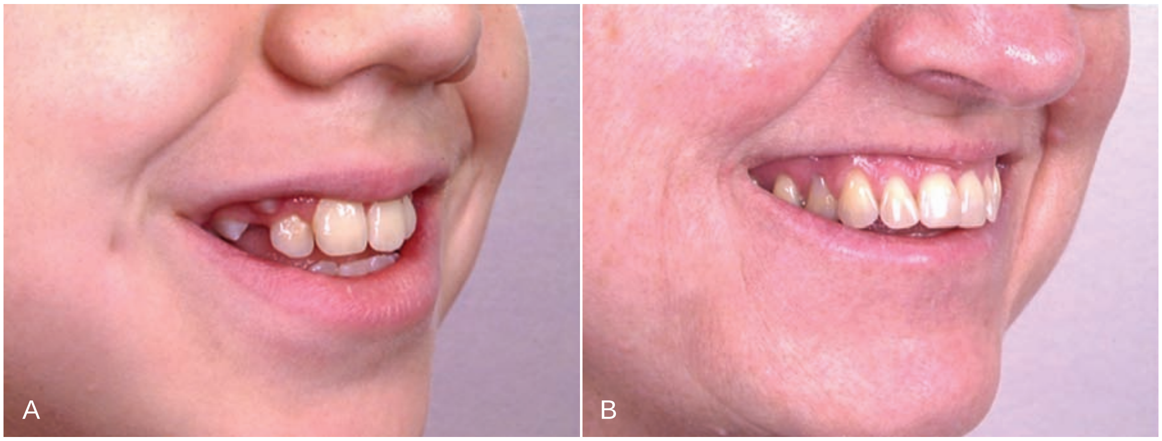


FIGURE 2-3 **A,** Close-up smile on oblique view represents a child presenting for correction of an open bite. **B,** The smile of his mother, who has an anteroposterior cant of the maxilla with the posterior maxilla clearly being inferiorly positioned and incomplete display of the anterior teeth. Note that the child has the same pattern.

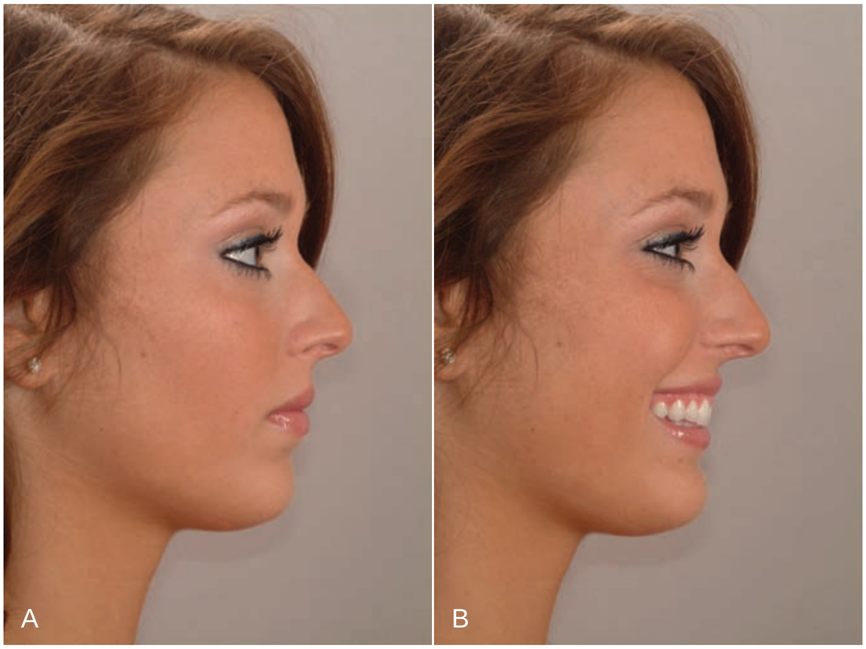


Figure 2-4 Two profile images are useful**. A,** Profile at rest with lips relaxed. **B,** Profile smile. This image provides a good view of maxillary incisor angulation and overjet in a way that patients see frequently, but clinicians often don't look at their patient's smiles in this orientation.

Two profile images are useful (see Figure 2-4):

a. *Profile at rest*. The lips should be relaxed. Lip strain is illustrated better in the frontal view, so a profile photograph with the lips strained in closure is unnecessary.

b. *Profile smile*. The profile smile image allows one to see the angulation of the maxillary incisors, an important aesthetic factor that patients see clearly and orthodontists tend to miss because the inclination noted on cephalometric radiographs may not represent what one sees on direct examination.

4. *An optional submental view* (Figure 2-5). Such a view may be taken to document mandibular asymmetry. In patients with asymmetries, submental views can be particularly revealing.

Digital Video Technology in Orthodontic Records. In standard photography, the image represents an approximate $\frac{1}{125}$-second exposure of a patient's smile. In recording a smile for subsequent analysis, the subject is asked to smile and the picture is snapped. The problem in this process lies in the knowledge that the lips start the smile process at rest and animate over a very short time period. The image is taken somewhere in this dynamic process and may not represent the patient's consistent and repeatable smile. In practical terms, the image may be taken halfway into the smile or halfway to the end of the smile and may not represent the smile the patient uses consistently. Certainly almost all practicing clinicians have had the frustrating experience of looking at the patient's smile image during treatment planning and having the subject show a forced smile or smiling without their teeth showing (Figure 2-6) (particularly 12-year-old boys!). The dynamic recording of smile and speech may be accomplished with digital videography. Digital video and computer technology currently enable the clinician to record anterior tooth display during speech and smiling at the equivalent of 30 frames per second. With video clips of this type, one can review the video clip on a computer screen for repeated playback or set up a printout sequence that reflects the "smile curve," which is a series of frames chosen to reflect the animation of the smile from start to finish (Figure 2-7). This gives the clinician an opportunity to both visualize the smile from start to finish in dynamic viewing and see the individual frames in sequence to visualize the sustained smile—the smile with the most consistent lip incisor position during the smile.

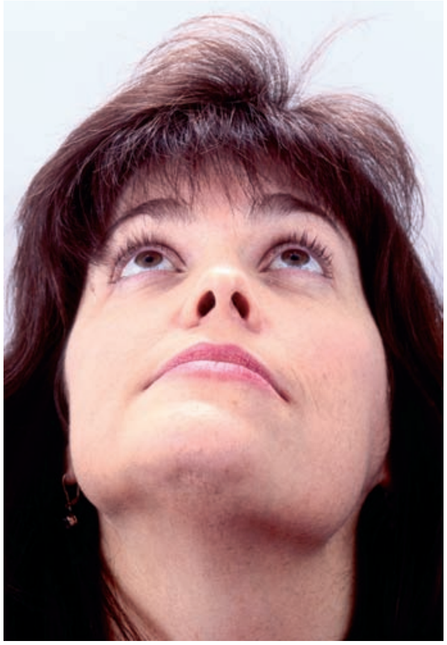


FIGURE 2-5 An optional submental view may be taken to evaluate and document mandibular asymmetries further.

Intraoral Photographs. Standard intraoral photographic series consists of five views: right and left lateral, anterior, and upper and lower occlusal (Figure 2-8). The occlusal photograph should be taken using a front surface mirror to permit a 90-degree view of the occlusal surface.

The orthodontist also can use specially designed mirrors that improve cheek retraction with the lateral views to obtain more direct views of buccal occlusion.

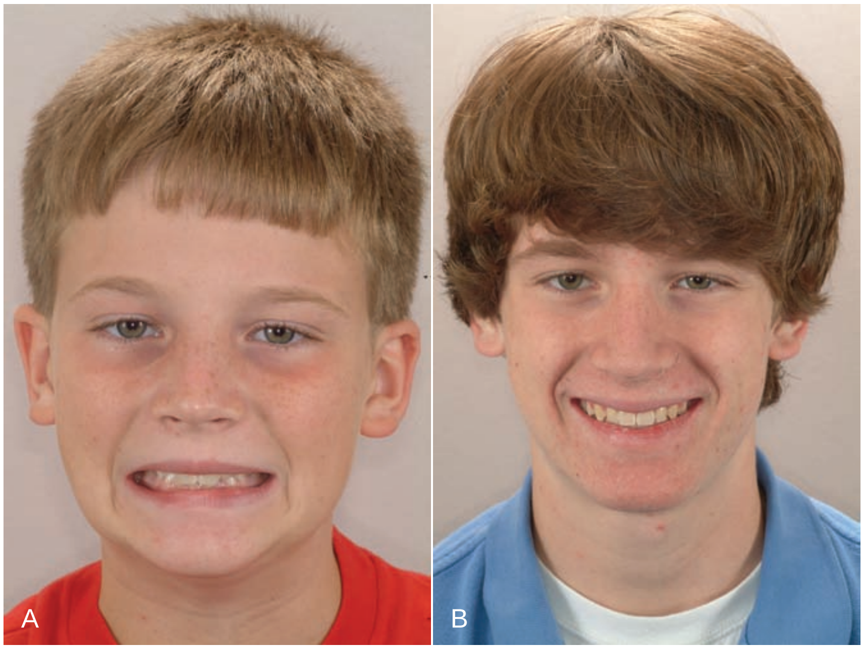


FIGURE 2-6 The frustrating experience for the clinician is attempting to obtain a natural and repeatable smile. **A,**This patient obviously presents a forced and unnatural appearance. **B,** The same patient at the end of treatment with a more natural smile.

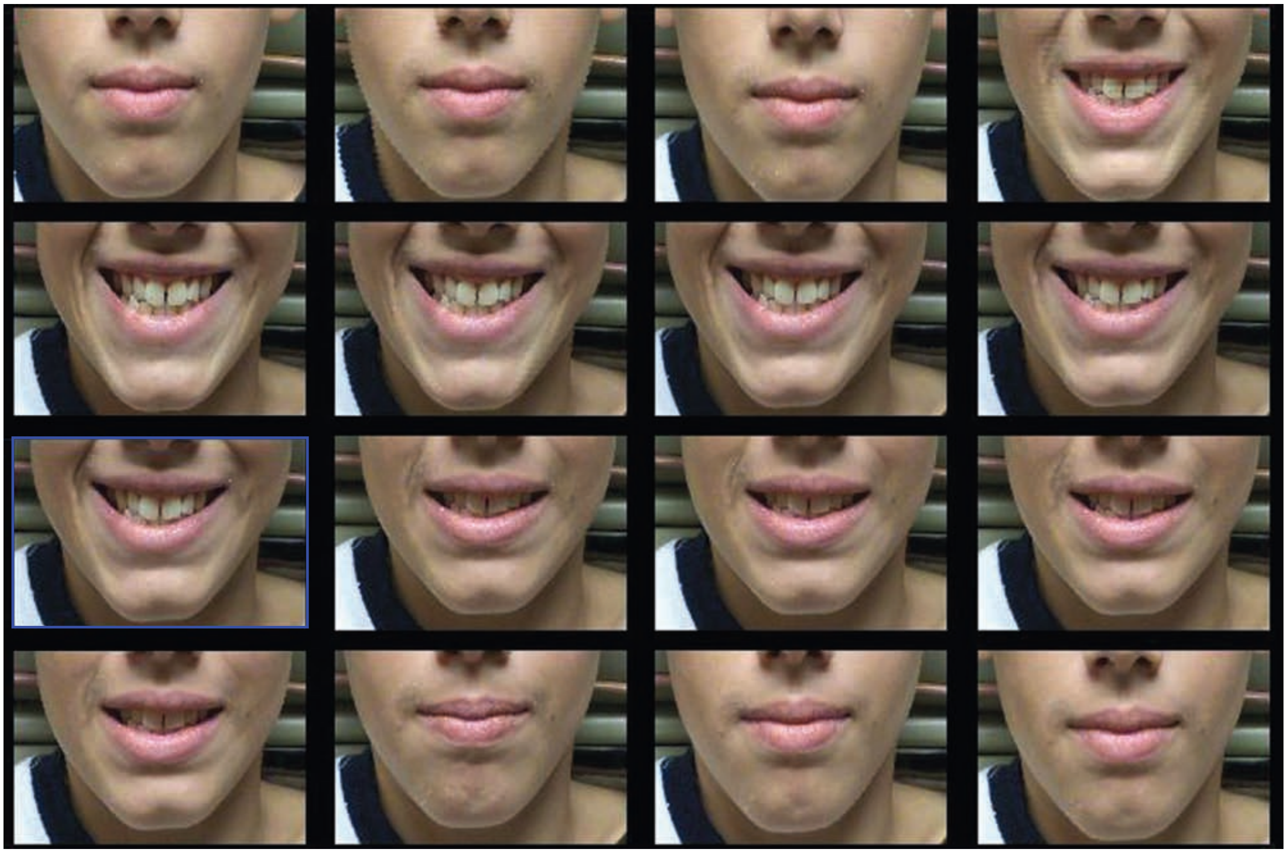


FIGURE 2-7 Mumper Digital video clips can be a useful adjunct in smile evaluation. Seeing the series of photographs allows the clinician to see the sustained smile, which we would accept as the posed smile.

To reflect buccal interdigitation accurately, as much cheek retraction as possible is needed, or one can use a mirror to gain a more direct view. A 45-degree view from the front makes a Class II malocclusion appear to be Class I. Because occlusal relationships are captured more accurately on casts, mirror views of the lateral occlusion are usually not absolutely necessary.

The major purpose of the intraoral photographs is to enable the orthodontist to review the hard and soft tissue findings from the clinical examination during analysis of all the diagnostic data. What is surprising is how often one discovers something on the photographs that was overlooked at the time of oral examination. Another purpose of the intraoral photograph is to record hard and soft tissue conditions as they exist before treatment. Photographs that show white-spot lesions of the enamel, hyperplastic areas, and gingival clefts are essential to document that such preexisting conditions are not caused by any subsequent orthodontic treatment. The authors also recommend, in addition to the standard intraoral images, close-up images taken with a black background for microesthetic evaluation (Figure 2-9). This is a standard view for cosmetic dentistry and demonstrates tooth shape more clearly, as well as other aesthetic considerations such as color, halos, embrasures, connectors, etc.

Cephalometric Radiographs. A lateral cephalometric radiograph is needed routinely. Lateral cephalograms have two purposes: (1) they reveal details of skeletal and dental relationships that cannot be observed in other ways, and (2) they allow a precise evaluation of response to treatment. In many instances, an adequate orthodontic diagnosis can be made without a cephalometric radiograph; however, accurate assessment of a patient's response to treatment is practically impossible without comparing cephalometric films before, during, and after treatment. For this reason, lateral cephalometric films are desirable but not always necessary. Many patients whose dental and skeletal relationships seem perfectly straightforward (e.g., Class I crowding problems) may not actually benefit from a cephalogram sufficiently to warrant the radiographic exposure involved. Treating skeletal malocclusions without cephalometric evaluation is a serious error.

The diagnostic value of lateral cephalometric films can be improved by taking the films with the patient in a natural head position rather than orienting the head to an anatomic plane as was done in the original cephalometric techniques.[2] Cephalometric head holders fix the patient's head at three points: the external auditory canals bilaterally and the bridge of the nose or forehead.

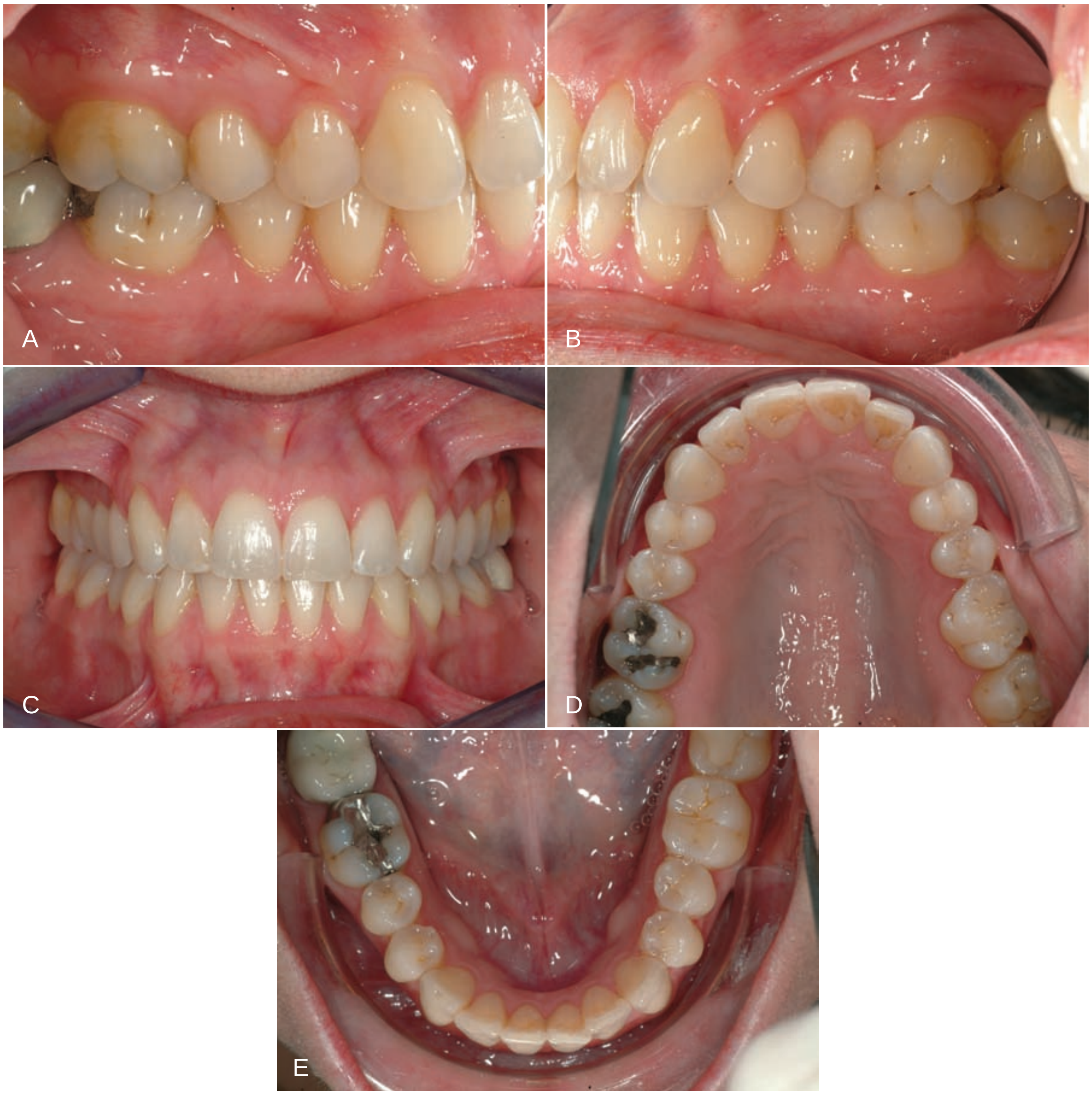


FIGURE 2-8 **A,** The frontal centered dental photograph, showing teeth and surrounding soft tissue and excluding retractors and lips. **B,** The right buccal dental photograph, mirror view. **C,** The left buccal dental photograph, mirror view. **D,** The maxillary occlusal dental photograph. **E,** The mandibular occlusal dental photograph.

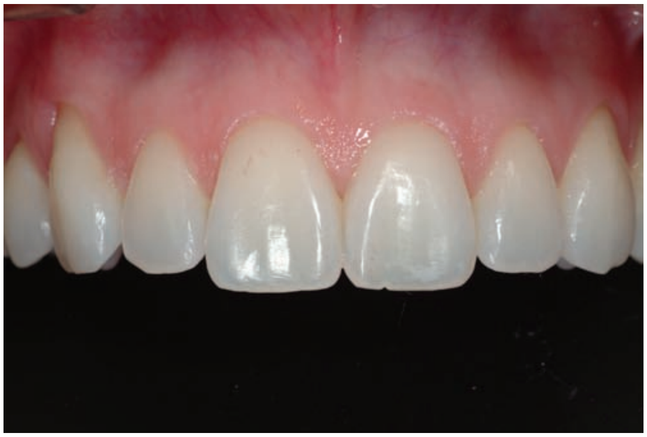


FIGURE 2-9 Close-up image with black background for microesthetic evaluation. This view demonstrates Microesthetic characteristics such as tooth shape, color, halos, embrasures, and connectors.

It is possible to obtain a natural head position cephalometric film, controlling both the source-to-subject and subject-to-film distances, without using a head holder at all.[5] Such films are made by having the patient orient the midline of the face (midsagittal plane) to the midsagittal plane of the head holder without actually attaching the head holder. For patients with growth deformities in which the ears are malpositioned, this may be the only feasible approach.

As a general guideline, differences between natural head position and Frankfort plane positioning are most likely to be encountered in patients with jaw discrepancies, so the further out the patient is on the deformity scale, the more important it is to use natural head position. In most patients, the difference between a natural head position film and an anatomically positioned one is in the vertical orientation of the head. The patient's head is positioned with the ear rods placed lightly into the ears, gently manipulated into a relaxed position as the patient looks into a mirror a few feet away or out a window at a distant horizon, and then fixed in the cephalostat. For greater diagnostic usefulness, the patient's lips should be relaxed rather than pulled into a strained closure when the cephalometric film is made. This step is particularly important when one contemplates a vertical repositioning of the teeth by orthodontic intrusion or extrusion or surgical repositioning of the segment. A number of the published soft tissue cephalometric analyses have been derived from cephalograms with the subject's lips in closed position even if strained. These analyses neglect the vertical component and may present a distorted view of the anteroposterior lip position because of the lip strain factor.

The teeth should be held lightly together in centric (habitual) occlusion when the cephalogram is obtained. If a severe centric relation–centric occlusion discrepancy exists, obtaining a second film with the mandible retruded may be helpful. However, getting the patient into a true centric relation position in the cephalometric head holder can be difficult. For this reason, the centric relation film is of less diagnostic value than might be thought initially, and taking two lateral head films rarely is indicated.

Contemporary Applications of Cephalometry. The original purpose of cephalometrics was for research on growth patterns and the craniofacial complex, but cephalometric radiographs came to be recognized as valuable tools in evaluating dentofacial proportions and clarifying the anatomic basis for malocclusion. Malocclusion is a result of an interaction between jaw and tooth position and the position the teeth assume as they erupt, which is in turn affected by the jaw relationships. For this reason, two apparently similar malocclusions as evaluated from dental casts may turn out to be different when evaluated more completely, using cephalometric analysis to reveal differences in dentofacial proportions.

Still another use for cephalometrics is to predict changes that should occur in the future for a patient. The result is an architectural plan or blueprint of orthodontic treatment called a visualized treatment objective (VTO). The accuracy of the prediction is a combination of the accuracy of predicting the effect of treatment procedures and the accuracy of predicting future growth. Unfortunately, growth predictions and predictions of the effects of treatment on growth remain relatively inaccurate, so a VTO for a growing child often is only a rough estimate of the actual outcome. Nevertheless, preparation of the VTO can be helpful in planning treatment for patients of any age with complex problems.

In contemporary patient analysis, the cephalogram is used as an initial diagnostic tool and in the integration of the VTO concept into image projection. The emphasis in this chapter is on the extension of this methodology in modern treatment planning. In modern orthodontics, cephalometric findings no longer are the major determinant of treatment goals.

Computer Imaging in Contemporary Treatment Planning. Patients are keenly interested in knowing what they will look like after treatment. Although profile line drawings based on manipulation of cephalometric tracings may provide a reasonable feedback system for the orthodontist, they have little cognitive value to the patient. Computerized cephalometric programs streamline the laborious manual measurement of dimensions and angular relationships on patient cephalograms and have made it much easier to create and use VTOs. Before the use of computers in the treatment planning process, the VTO concept required the clinician to use acetate templates of the teeth and jaws to predict what treatment was needed to attain aesthetic and functional goals. Computer imaging technology now allows clinicians to modify facial images to project treatment goals accurately and discuss them with patients. The computer image is much easier for the patient to comprehend than just the soft tissue profile of a cephalometric tracing. Computer imaging is the next step in the natural progression of the application of technology to orthodontic treatment planning.

For this purpose, integrated profile image–cephalometric planning offers several advantages:

1. Profile visualization for better comprehension of the facial response to the dental and soft tissue manipulation involved in a particular treatment plan
2. Quantification of the planned dental and osseous movements to reduce the guesswork regarding the facial response to the proposed orthodontic treatment plan
3. Evaluation of various treatment plans before deciding on the final plan

This is the essence of the concept of image-directed diagnosis because it allows clinicians, at least in adult or surgical cases, to determine beforehand the facial result of proposed treatment.

A VTO is mandatory in the development of a surgical-orthodontic treatment plan in which growth effects are not a problem (Figure 2-10). Many surgeons are leery of the use of providing imaging projections of preoperative surgical projections out of the fear that it represents an implied warranty or that a lawsuit may result if the result does not match closely. Studies indicate the opposite,[8] in which patients are more satisfied with their final outcome when their presurgical counseling included imaging than those who did not. In addition, all patients in one study indicated that they actually liked the final result better than the image projection.[9]

Computer imaging also is useful in counseling and communicating with patients because it allows presentation of treatment options that are often difficult to explain verbally. The counseling phase involves the use

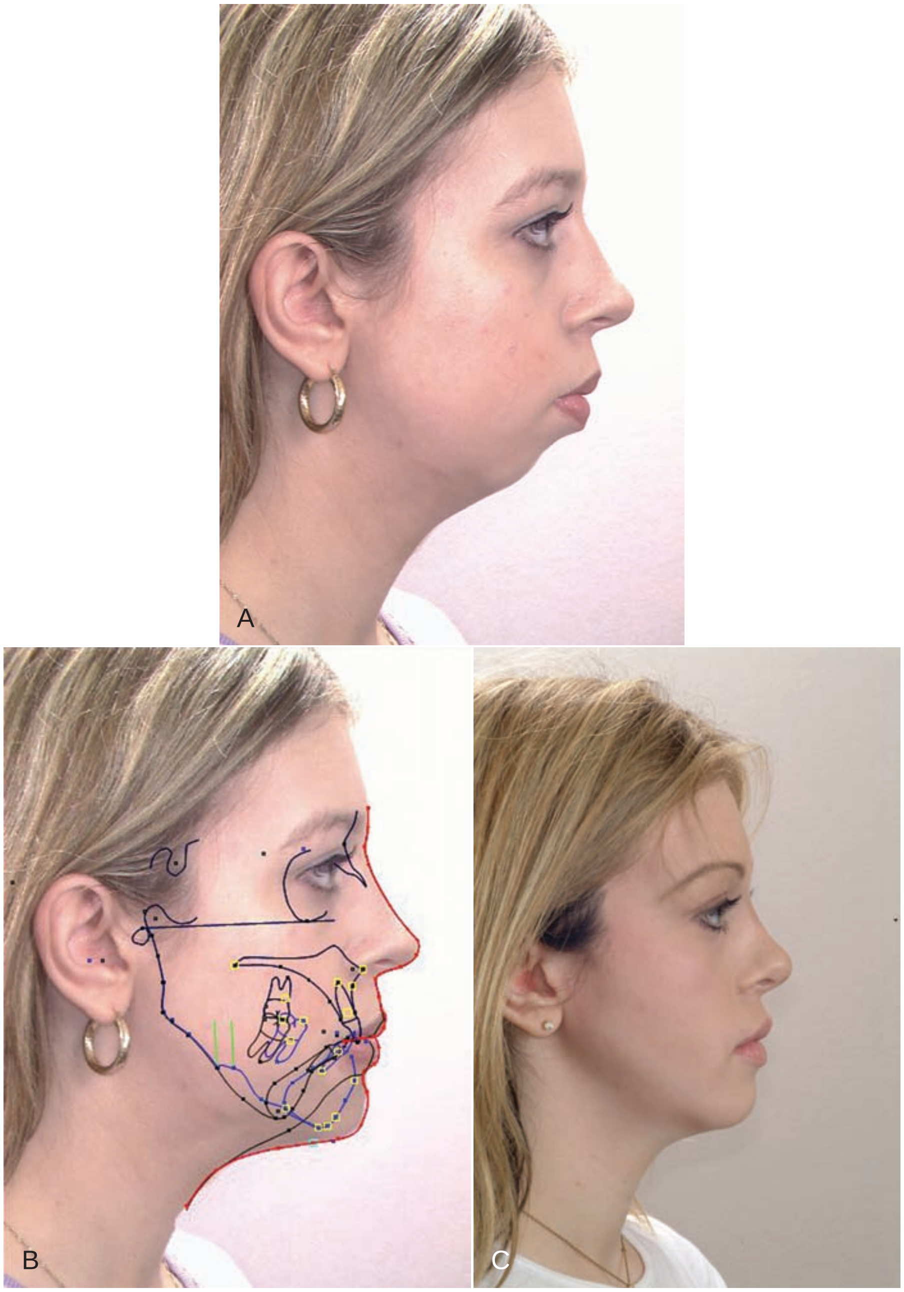


FIGURE 2-10 **A,** Initial profile image of patient being evaluated for extraction of lower premolars and advancement of the mandible and chin**. B,** Visualized treatment objective (VTO) of patient demonstrating the soft tissue outline anticipated with these orthodontic and surgical movements, and the amount of movement is retroengineered through a quantitative table reflecting the exact magnitude of movement. **C,** Final profile image reflects the outcome and its proximity to the VTO.

of facial- or dental-image modification without any quantitative aspect to the process. This modification is a graphic way of communicating concepts that are difficult to present verbally. For example, facial imaging and a smile bank can be used to explain to patients how their teeth will look after straightening. A sample of smiles with aligned teeth can be used to demonstrate to patients the changes in their dental appearance they may expect. This process, which is facilitated greatly by the use of computer images, improves the chance of true informed consent.

After the patient decides to proceed with treatment, the clinician must consider ways to maximize the chance of actually producing the outcome the patient desired. The planning phase of computer imaging permits quantification of the treatment plan so that the clinician knows precisely what and how much to do. The principle of quantification and retroengineering as described in the surgical VTO section is also important in smile design. Calibration of a smile image and the ability to measure the amount of change needed to reach smile goals are recent developments (Figure 2-11).

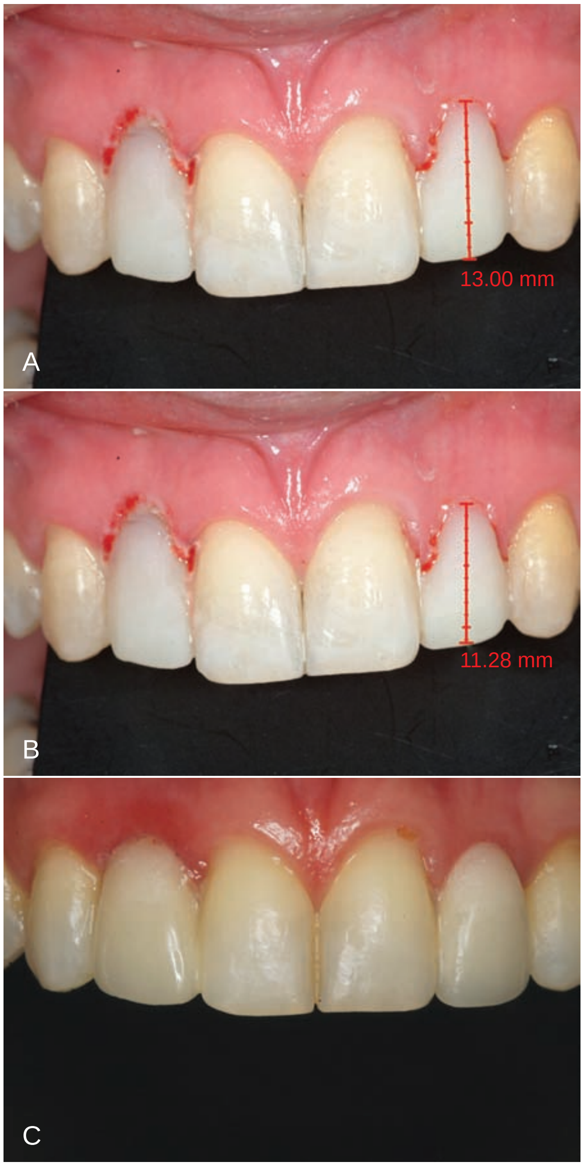


FIGURE 2-11 **A,** Calibrated image of patient in preparation for replacement of missing laterals with fiber-reinforced bonded bridges. The gingival margin of the lateral pontic was more apical than the ideal placement. In communication with both restorative dentist and the laboratory, this close-up image was first calibrated and the pontic length measured (13 mm). **B,** Using "cut and paste" image modification, the gingival margin of the lateral incisor pontic was moved incisally to a position slightly below the gingival margins of the adjacent teeth. The pontic image was remeasured in order to quantify the desired pontic height to the restorative dentist and laboratory. **C,** The final restoration demonstrating the desired change.

CLINICAL EXAMINATION OF FACIAL SYMMETRY AND PROPORTION: ITS SIGNIFICANCE IN TREATMENT PLANNING

The clinical examination requires direct measurement of a number of hard and soft tissue relationships, most of which cannot be documented in any form of imaging or models. After the clinical examination data are entered into a database program, the data become as easily retrieved and used as any other digital record.

Application of Database Programs to Clinical Information

The goal of orthodontic diagnosis, as stated previously, is to determine the patient's chief complaint and give it the highest priority in designing treatment. Identification of the patient's problems and specifying potential solutions have been the major focuses of diagnostic efforts.

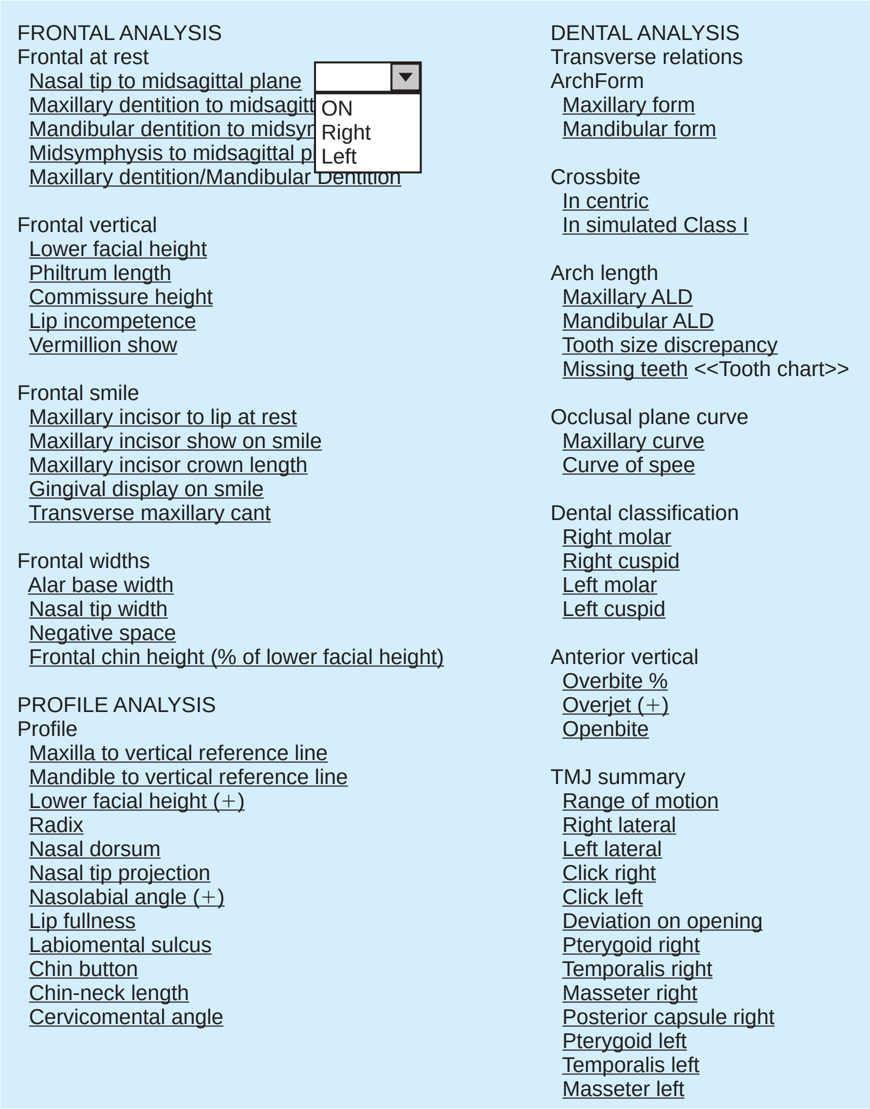
In contemporary diagnosis, however, orthodontists now include the concept of ***treatment optimization.*** The term "optimization" has become familiar to most orthodontists through the increased use of computer technology. With computer hardware, it is wise periodically to "optimize the hard drive" on your computer to keep it running at its top performance level. What this does is scan the computer disc for damaged or corrupted files and eradicate them. The process also identifies good files and keeps them. Treatment plan optimization is similar. Optimization means that the orthodontist assesses the patient's problems and identifies ways to eliminate them and then identifies the patient's positive attributes and designs treatment to keep them. A familiar example in orthodontics is the correction of Class II malocclusion in a patient with mandibular deficiency and a normal upper face. Extraction of maxillary first premolars and retraction of the upper incisors solves the problem of the Class II malocclusion but ignores the positive attribute of a normal upper face, and the patient then has the normal upper lip retracted and flattened to fit the distorted lower jaw. The more appropriate treatment plan is advancement of the deficient mandible, correcting the Class II malocclusion and maintaining the normal upper face.

The problem-oriented treatment-planning process is especially useful in this context because it demands a systematic and thorough approach to evaluation. The generation of the problem list then leads to the diagnosis, and treatment options for each problem lead to a logical treatment plan. In clinical practice, this methodical process may give way to expedience, and the clinician may fall back on "techniques" and treatment "systems" rather than individualized treatment plans carefully derived for each patient. The evolution of computer technology has facilitated this process so that the clinician can organize the information to be used in the decision-making process in a streamlined fashion without getting lost in the details.

Database programs work by setting up fields that represent sections of data entry. The data fields allow orthodontists to preload choices through the use of pop-up windows. The database program is designed to facilitate everyday functions in the problem-oriented diagnostic and treatment planning process:

1. *The information-gathering process is thorough but streamlined*. In the traditional examination, measurements are written down on a sheet of paper and then transcribed or dictated into a planning format. The database program facilitates this process by using the computer screen interface as the entry point (Figure 2-12). Pop-up menus are used for entering data. As the computer cursor is placed on one of the data entry levels, a pop-up box with a number of choices appears, beginning with the most common choice at the top (most easily accessed for entry). As soon as a choice is identified and clicked with the mouse, the menu box closes and the next one is opened, complete with choices. In the clinical setting, this is usually the function of a staff auxiliary member, such as a treatment coordinator. For example, when the field "nasolabial angle," is clicked, a small window with the choices of "obtuse," "normal," and "acute" appears next to the nasolabial angle field, and the clinician can identify the choice by clicking it with a pointing device. After the selection is made, the program moves immediately to the next choice. This greatly streamlines the examination process and forces the clinician to measure each detail of the dentofacial analysis.

The first patient appraisal should be thorough and consistent, maximizing the chance that nothing of importance will be overlooked. Examiners should avoid situations in which they perform a cursory examination, jotting down notes regarding abnormalities they see and not really making note of any



FRONTAL ANALYSIS
Frontal at rest
Nasal tip to midsagittal plane
Maxillary dentition to midsagitt
Mandibular dentition to midsyr
Midsymphysis to midsagittal p
Maxillary dentition/Mandibular Dentition

Frontal vertical
Lower facial height
Philtrum length
Commissure height
Lip incompetence
Vermillion show

Frontal smile
Maxillary incisor to lip at rest
Maxillary incisor show on smile
Maxillary incisor crown length
Gingival display on smile
Transverse maxillary cant

Frontal widths
Alar base width
Nasal tip width
Negative space
Frontal chin height (% of lower facial height)

PROFILE ANALYSIS
Profile
Maxilla to vertical reference line
Mandible to vertical reference line
Lower facial height (+)
Radix
Nasal dorsum
Nasal tip projection
Nasolabial angle (+)
Lip fullness
Labiomental sulcus
Chin button
Chin-neck length
Cervicomental angle

DENTAL ANALYSIS
Transverse relations
ArchForm
Maxillary form
Mandibular form

Crossbite
In centric
In simulated Class I

Arch length
Maxillary ALD
Mandibular ALD
Tooth size discrepancy
Missing teeth <<Tooth chart>>

Occlusal plane curve
Maxillary curve
Curve of spee

Dental classification
Right molar
Right cuspid
Left molar
Left cuspid

Anterior vertical
Overbite %
Overjet (+)
Openbite

TMJ summary
Range of motion
Right lateral
Left lateral
Click right
Click left
Deviation on opening
Pterygoid right
Temporalis right
Masseter right
Posterior capsule right
Pterygoid left
Temporalis left
Masseter left

FIGURE 2-12 Database programs facilitate the data-gathering process by using the computer screen interface as the entry point. All components of the clinical examination are displayed on one screen, as in this screen shot, and as the clinician goes through the examination process and calls off each measurement, the data are entered through the use of pop-up menus. The pop-up menus allow data entry, and as each entry is made, the window closes and automatically opens the next for a smooth and rapid transition from one parameter to the next. This process facilitates a thorough examination and evaluation.

other descriptive data, normal or abnormal. Practitioners may assume that most diagnostic decisions can be made from the records they take of patients. Is that bad? Yes, it is, and for several reasons.

a. Static records cannot reflect the dynamic relationships that are important in the overall functional and aesthetic assessment of the patient. For example, the relationship of the upper incisor at rest and on smile is not reflected in radiographs or models and is evaluated poorly in photographs. As described previously in this chapter, dynamic (video) records help but still do not replace careful clinical observation.
b. The comprehensive facial and dental analysis process is streamlined and enhanced greatly by the database program.
c. The notation of normal observations is a powerful medicolegal aid. An unhappy patient may begin to "pick apart" the outcome, and the well-prepared practitioner should be able to document treatment changes with as many observations as possible.

Orthodontists currently enter this information into a computer in the examination room, but other options include the use of laptop and notebook computers. The use of personal digital assistants also is evolving. A handheld personal digital assistant permits even greater mobility, allowing data entry at chairside or any other location in the office or in auxiliary offices. Data may be entered with an electronic pen rather than a mouse and keyboard.

2. *The problem list is generated automatically through the use of predetermined parameters.* Each data entry is processed through the parameter field set by the clinician to test for its range of normality. For example, in the measurement of the maxillary midline to the midsagittal plane, the midline is coincident with the midsagittal plane or it is not. If the midline is not coincident, it is automatically a problem and is identified as such by the software and dropped into the problem list of the appropriate area (in this case, frontal facial examination). In more complex measurements, one may place ranges. For example, a mandibular plane measurement greater than 37 degrees is identified as a high mandibular plane angle; a measurement less than 32 degrees is identified as a low mandibular plane angle. Measurements may be changed by clinicians to fit their ranges because all doctors have their own parameters of what they consider problematic.
3. *Access to information is enhanced greatly in the traditional examination and treatment planning process.* After the clinical examination is finished, the observations then are transcribed into a more formal record system or left on the sheet to be retrieved from the chart when needed. This means that one of three things happens:

a. If the information is left as is, it is not recalled easily during treatment because the information is not easily accessible. Also, the information is not transmitted easily to or shared with other doctors or with patients.
b. The doctor writes the notes in a more organized fashion, which is time consuming to complete.
c. If the record is dictated, the doctor's time involvement is reduced significantly because dictation is much faster than handwriting. However, staff time then is needed to transcribe the dictation; therefore, elimination of the dictation is desirable if possible.

Database programs require entry of information only one time, and this information can be retrieved and transported into any document, transported into spreadsheets for research purposes, or recalled for the clinician at any time on computer screens in the clinic, consultation area, or even at home.

Frontal Vertical Facial Relationships

Attractive faces tend to have common proportions and relationships that generally differ from normative values. Treatment planning in the past focused on linear and angular measurements, while the trend today is to recognize the interrelationships of proportions. The ideal face is divided vertically into equal thirds by horizontal lines adjacent to the hairline, the nasal base, and menton (Figure 2-13). This figure also illustrates two other

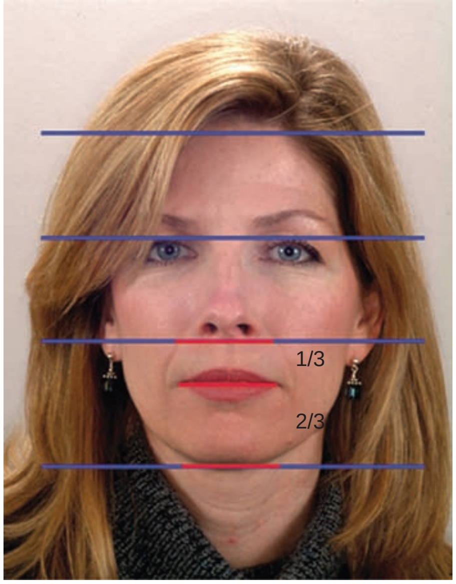


FIGURE 2-13 Frontal vertical thirds of the ideal female face with ideal symmetry. The vertical thirds should be roughly equal, with the lower third further subdivided into an upper third and lower two thirds. In the adult, philtrum height should be equal roughly to commissure height.

characteristics of the ideal lower third of the face: the upper lip makes up the upper third and the lower lip and chin comprise the lower two thirds. What has become increasingly important is to recognize not just the vertical relations, but the relationship to the facial widths—the height-to-width ratio.

Increased Face Height. The patient in Figure 2-14, *A* and *B*, is a good example of vertical maxillary excess (VME). In addition to the long upper third, this patient had a long lower face with excessive incisor at rest, excessive gingival display on smile, and interlabial gap—all of which are characteristics of VME. Surgical correction of the skeletal deformity was performed through superior repositioning of the maxilla, which also dramatically shortened the lower face (Figure 2-14, *C*) The gummy smile also was improved with the procedure (Figure 2-14, *D*), and an advancement genioplasty with vertical shortening contributed to the shortening of the lower facial third.

Does a patient with a long lower face always represent a VME problem? Of course not. Figure 2-15, *A*, presents an example of excessive vertical disproportionality of the lower facial height resulting from excessive chin height. Pretreatment facial analysis revealed an excessive lower

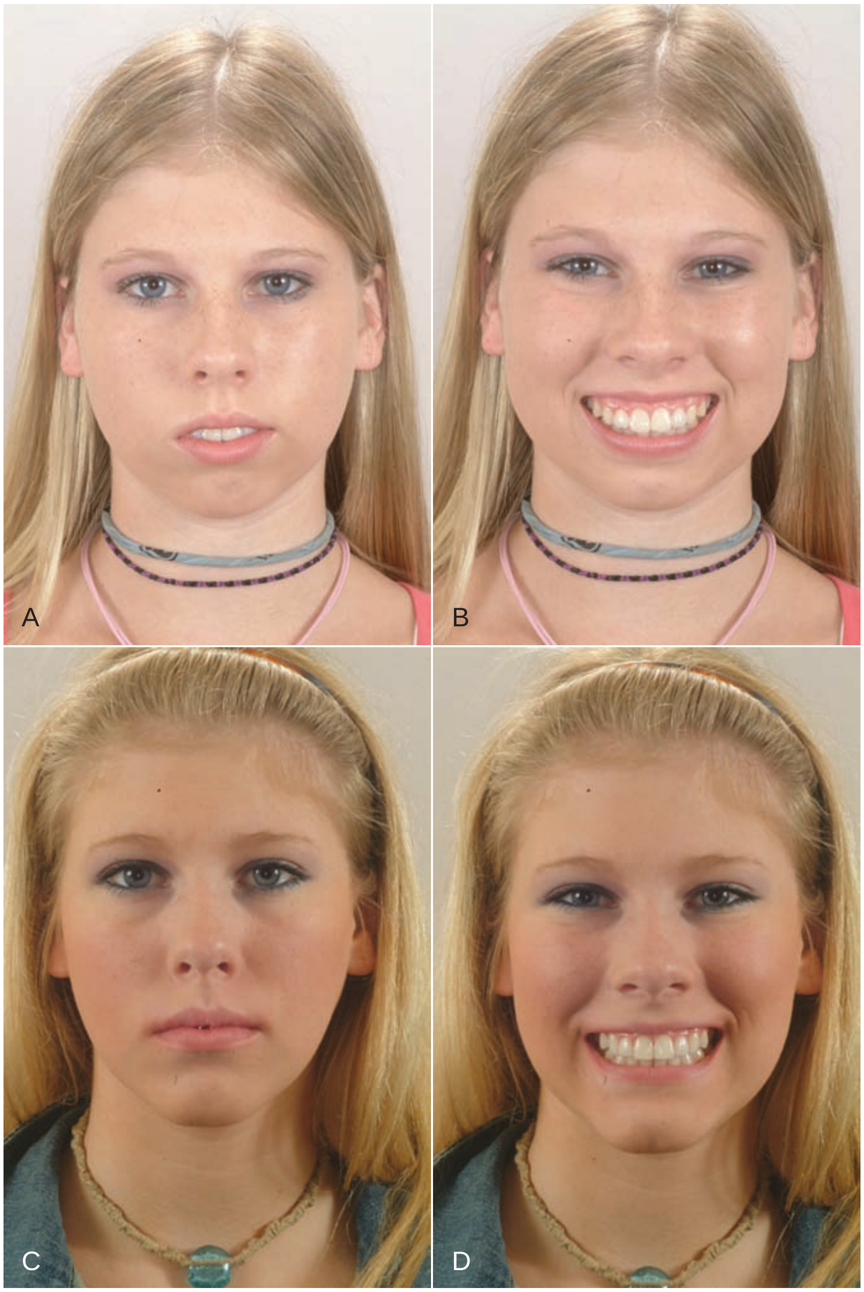


FIGURE 2-14 Pretreatment (**A** and **B**) and posttreatment (**C** and **D**) facial views of a patient with the characteristics of vertical maxillary excess: a long lower facial height, excessive incisor display at rest, interlabial gap and excessive gingival display on smile.

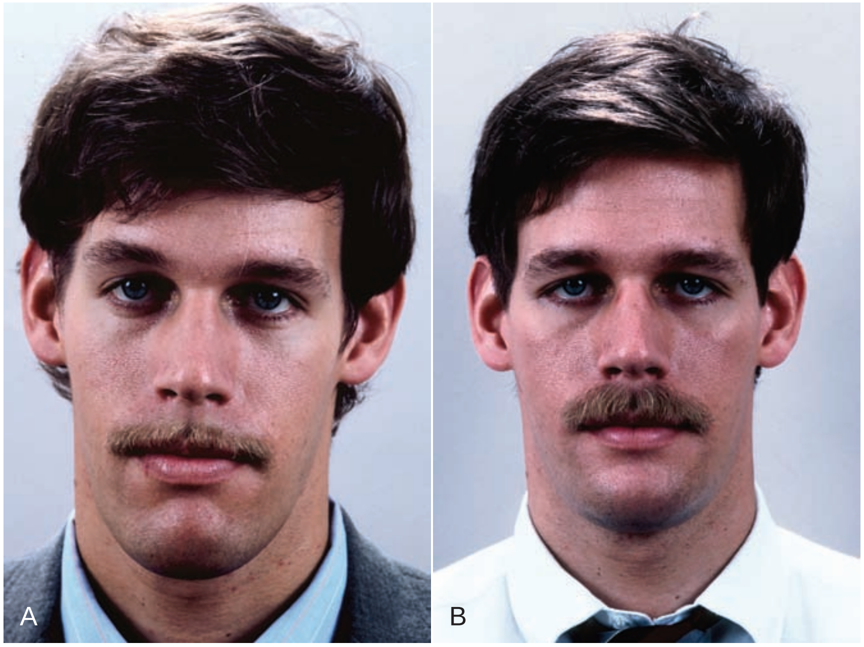


FIGURE 2-15 Before treatment **(A),** this patient had excessive lower facial height. The upper incisor-to-lip relationships were normal, which eliminated vertical maxillary excess as a potential cause of the long lower facial height. The chin height was 75% of the lower facial third, so more ideal facial proportions **(B)** were achieved with an inferior border osteotomy and removal of a wedge of bone above the chin to reduce chin height. *(From Sarver DM:* Esthetic orthodontics and orthognathic surgery, *St Louis, 1998, Mosby.)*

facial height with normal upper facial thirds. An initial diagnosis of VME was considered, along with the possibility of surgical maxillary impaction. However, the patient had a normal smile line and a normal relationship between the resting upper lip and incisor, which is not associated with VME. The chin height from menton to the lower vermilion was significantly greater than the desired two thirds of the total height of the lower facial third. This clinical assessment led to the conclusion that the vertical facial disproportionality resulted primarily from excessive chin height rather than VME. The treatment prescribed consisted of a wedge osteotomy and skeletal shortening of the chin to reduce the lower facial height (Figure 2-15, *B*).

Decreased Face Height. Short lower facial height can result from vertical maxillary deficiency, mandibular deficiency with diminished mandibular body or ramus height, or a short chin height. Characteristics of vertical maxillary deficiency include (1) insufficient incisor display at rest, (2) inadequate upper incisor display on smile, and (3) short lower facial height. Improvement in the adult often includes surgical maxillary downgraft. This surgical procedure lengthens the midface and rotates the chin down as the mandible hinges around the condylar axis.

The patient in Figure 2-16, *A* and *B*, presented with a disproportionately short lower facial third and mandibular deficiency. Clinically, he had diminished incisor display at rest, and on smile, characteristic of vertical maxillary deficiency. Dentally, he had a Class II malocclusion, a deep overbite, and 9 mm of overjet. Surgical correction was required, consisting of maxillary downgraft and mandibular advancement to correct his malocclusion, improve proportionality of his lower facial third, and increase incisor display at rest and on smile (Figure 2-16, *C* and *D*).

Lower facial height increase in the adolescent may be improved through modification of growth, dental eruption, or both. Some examples of the ways this may be achieved, ranked in order of effectiveness, include the following:

1. *Functional growth modification appliances that increase lower facial height by promoting posterior dentoalveolar eruption.* Eruption occurs more rapidly in some patients than in others and is affected by the amount of freeway space, resting mandibular posture, and amount of wear. This type of treatment is most effective in younger patients in active phases of growth.
2. *Anterior bite plates incorporated into fixed appliances (such as a Nance-type appliance) or removable appliances.* Anterior bite plates hold the lower incisors against the acrylic while permitting the posterior teeth to erupt freely. The bite plate must be worn continually and also should be worn even after bite opening to maintain the increase in facial height and bite opening.
3. *Cervical headgear to encourage maxillary posterior eruption during growth modification.* Cervical

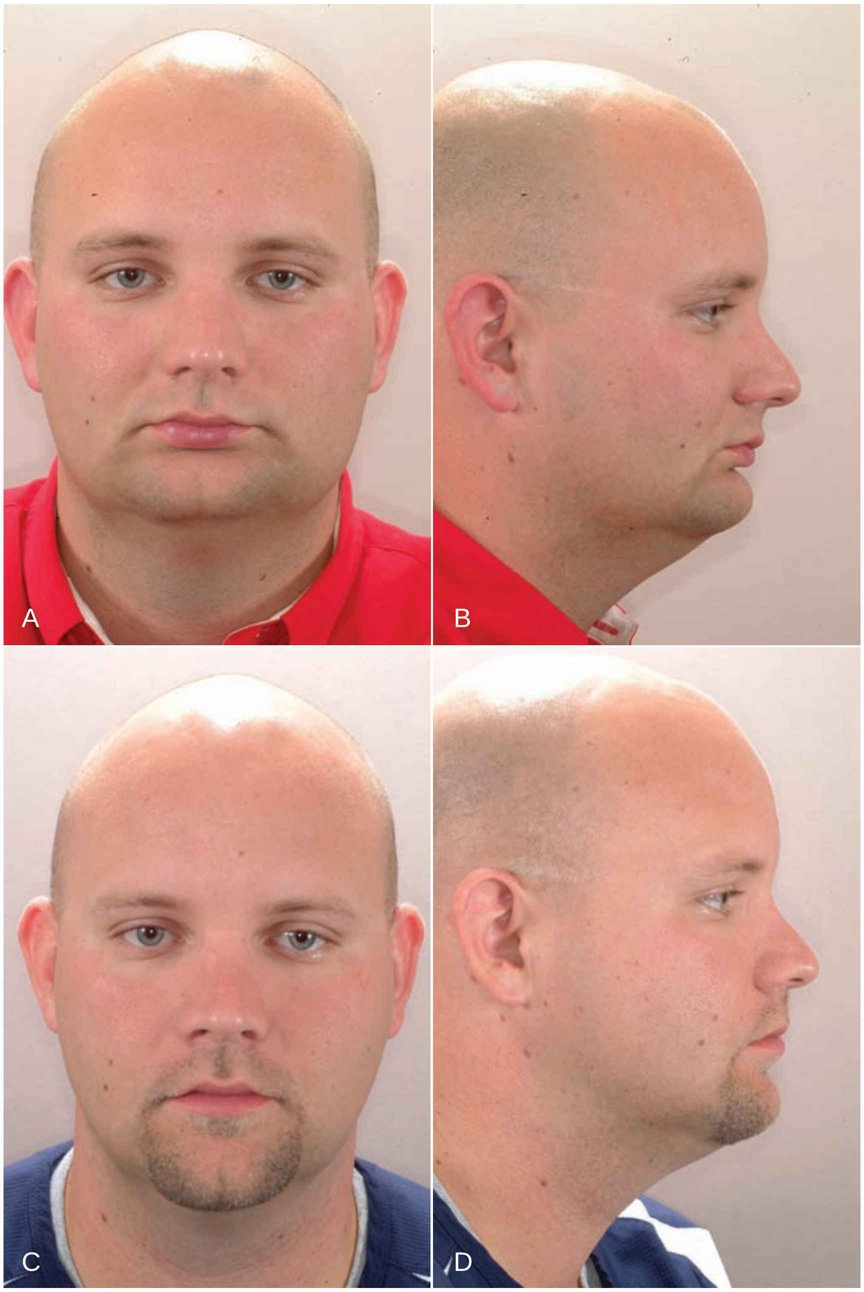


FIGURE 2-16 This adult patient presented with a short lower facial height, insufficient incisor display at rest and on smile, a deep bite, and a Class II malocclusion (**A** and **B**). A maxillary downgraft procedure was performed in addition to mandibular advancement surgery to achieve the desired increase in facial height (**C** and **D**).

headgear produces an extraoral force in a posterior and inferior direction below the center of resistance of the teeth and the maxilla, resulting in dentoskeletal extrusion and an increase in lower facial height.

4. *Reverse-curve arch wire mechanics designed to extrude the mandibular posterior segments.* A reverse curve of Spee commonly is placed in the lower arch wire to open the bite through some lower incisor intrusion and a more substantial amount of posterior extrusion, resulting in an increase in the lower facial height (Figure 2-17).

The analysis of the vertical thirds of the face is an initial barometer of the skeletal structures of the face and serves the clinician well by focusing on the face before the teeth, allowing observation of the gross proportionality of the face before the details are addressed.

Transverse Facial and Dental Proportions

The interrelationships of the widths of the components of the face are important in the overall proportionality of the face (Figure 2-18). Few linear or angular

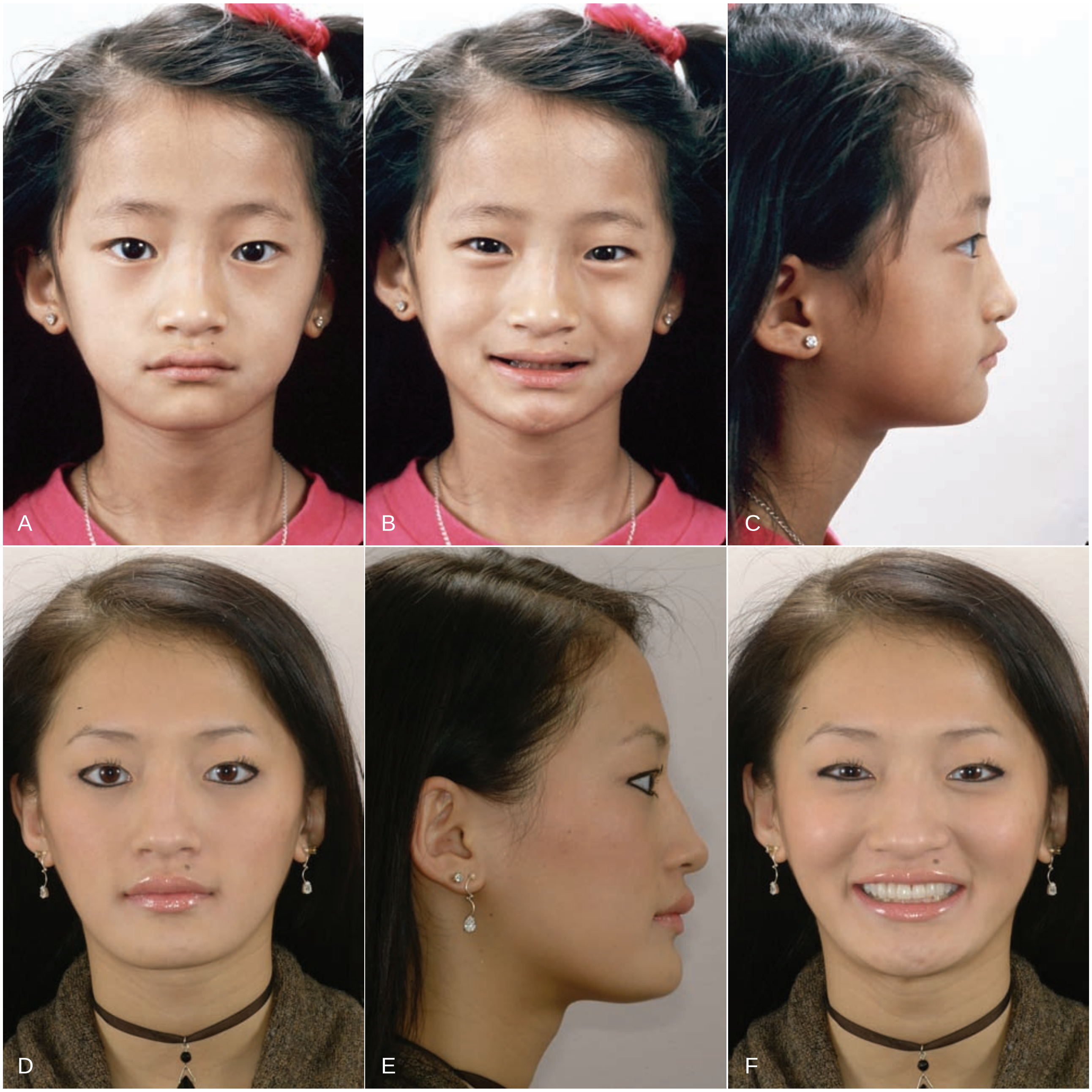


FIGURE 2-17 This patient represents a short face, deep bite patient in whom facial characteristics direct the orthodontic mechanics for occlusal correction, facial improvement, and restoration of malformed teeth. **A,** Her frontal relationships were characterized by a short lower facial third and an overclosed facial appearance. **B,** On smile, she did not display all of her maxillary incisor due to mild vertical maxillary deficiency and tooth malformation. **C,** Her profile was characterized by moderate mandibular deficiency and an acute nasolabial angle. Her short lower facial height and overclosed appearance was also apparent on profile. **D,** After 24 months of treatment, her lower facial height was dramatically improved. **E,** The profile also reflected growth modification with improvement in mandibular projection and increase in lower facial height. Lower facial height increase was achieved with cervical headgear and posterior extrusive mandibular arch mechanics. **F,** After restoration of the malformed teeth, incisor display was dramatically improved.

"normative" measurements or values are available because the interrelationship of these component parts is what is most important. For example, a vertically long, oval face most often is correlated with narrow gonial angles and a narrow nose. A wide nose on a narrow face tends to appear most noticeable and incongruous with the facial type described.

Central Fifth of the Face. The central fifth of the face is delineated by the inner canthi of the eyes. The inner canthus of the eye is the inner corner of the eye

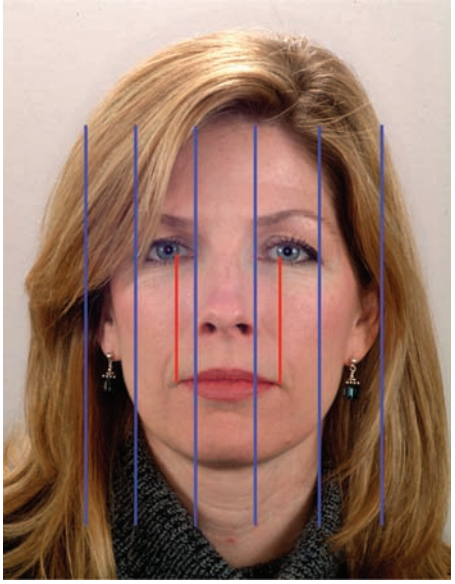


FIGURE 2-18 Sagittal facial proportions: the rule of fifths. From the midsagittal plane, the ideal face is composed of equal fifths, all approximately equal to one eye width. The commissure width should also be coincident with the medial limbus of the eyes, and the alar width should be coincident with the intercanthal distance.

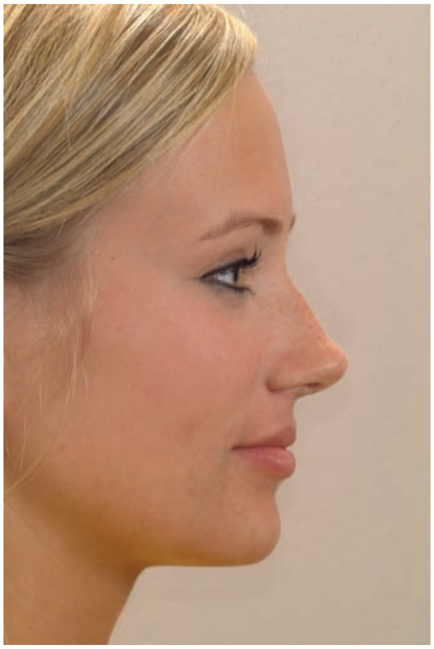


FIGURE 2-19 Profile of a patient with ideal nasal anatomy, illustrating the nasofrontal angle (radix), supratip break, double break of the nasal tip, and the nasolabial angle.

containing the lacrimal duct. A vertical line from the inner canthus should be coincident with the ala of the base of the nose.

Medial Two Fifths of the Face. A vertical line from the outer canthi of the eyes should be coincident with the gonial angles of the mandible. Disproportionality is a subtle clinical judgment, but procedures to augment or reduce the prominence of the lateral mandibular area are available to improve aesthetic problems here.

Outer Two Fifths of the Face. The outer two fifths of the face are measured from the base of ear to the helix of the ear, which represents the width of the ears. Unless this abnormality is part of the chief complaint, prominent ears are often the most difficult abnormality to discuss with a patient because only in the most severe cases do lay persons recognize their effect on the face. Otoplastic surgical procedures are relatively atraumatic and can improve facial appearance dramatically. They may be recommended to and performed on adolescents and adults, but changing the hairstyle to conceal the ear may be a more practical solution.

Evaluation of Nasal Proportions

The nose dominates the middle portion of the face on profile (Figure 2-19) but is an area that has not been emphasized in orthodontic training. A number of articles in the orthodontic literature have not received the attention from orthodontists they deserve (See the Suggested Readings at the end of the chapter). This is probably because many orthodontists are uncomfortable talking to patients about their noses when the main focus of the patient and the orthodontist is the teeth.

Orthodontic treatment plans and mechanics can affect dramatically the way the nose fits the face. In addition, nasal growth in the adolescent can produce changes that diminish the aesthetic result as the patient matures. The orthodontist needs to understand nasal anatomy and the treatment of nasal deformities well enough to be comfortable with discussions of nasal morphology, recognition of aesthetic problems, and potential treatment.

Radix. On profile, the radix is the area orthodontists generally associate with soft tissue nasion. Radix projection is a discrete but important aspect of nasal aesthetics and is quantified in terms of the nasofrontal angle. Lack of radix projection can make an otherwise normal nose appear to have a dorsal hump.

Nasal Dorsum. One third to one half of the nasal dorsum is called the bony dorsum because it is formed by the confluence of the two nasal bones. The rest is called the cartilaginous dorsum or septal dorsum because it is composed of septal cartilage. The septal cartilage combines with the bony nasal septum to divide the nasal cavity into two chambers. On profile, the septal cartilage protrudes in front of the piriform aperture. Most nasal humps are formed by the dorsal border of the septal cartilage in combination with the nasal bones. The removal of an overprojected dorsal hump is one of the most common and familiar of rhinoplastic procedures.

Nasal Tip. The nasal tip is the most anterior point of the nose, and the supratip is just cephalic to the tip. The supratip break is the area just cephalic to the nasal tip where the lobule meets the dorsal portion of the nose. On the aesthetic nose, a slight depression is present on the supratip, which should be more pronounced in the female than in the male. The double break represents the angular formation of the nasal tip created by the distinct definition of the tip cartilages created by the supratip, tip, and infratip.

Columella. The columella is the portion of the nose between the base of the nose (subspinale) and the nasal tip. The columella comprises the cartilaginous nasal septum and membranous septum.

Nasolabial Angle. The nasolabial angle measures the inclination of the columella in relation to the upper lip. The angle should be in the range of 90 to 120 degrees.[1] The morphology of the nasolabial angle is a function of several anatomic features. Procumbency of the maxilla tends to produce an acute nasolabial angle, and maxillary retrusion tends to produce an obtuse nasolabial angle, but the angle is very much affected by nasal form itself.

Lip Projection

Although lip projection appears to be a fairly simple concept, it is a more complex issue in the comprehensive facial analysis. Attempts have been made to quantify lip projection in the orthodontic literature by measurements such as the Rickett's E (aesthetic) line and Holdaway's line. These measurements are dentally oriented and are not facially comprehensive. For example, it often is stated that in an ideal E-line relationship, the lower lip should be coincident with a line from the nasal tip to the anterior chin, and the upper lip should be about 1 mm behind it. If a patient has a long nose, the E-line describes the problem as dental or maxillomandibular retrusion rather than nasal overprojection.

Lip projection is a function of the following:

- *Lip thickness:* Lip thickness is affected directly by patient age, gender, and ethnicity.
- *Dental protrusion or retrusion:* Hard tissue support of the lips is a recognized determinant of lip position.
- *Maxillomandibular protrusion or retrusion*

Excessive versus Inadequate Lip Projection. Lip projection is difficult to quantify because of its close interrelationship with other structures. Measurement of lip thickness is possible, and enough studies have been published in the literature to provide a sufficient database for this measurement. Lip thickness and its relation to other facial structures heavily influence the perception of lip projection. For example, in a patient with a deficient chin, the lower lip may appear full or procumbent. Advancement of the chin may result in better balance of the lower face and diminish the protrusive appearance of the lips.

The patient in Figure 2-20 is a good example of this interplay of anatomy. This young man was referred for correction of his mild Class II malocclusion. His parents thought that he had protrusive lips (Figure 2-20, *A*). His profile (Figure 2-20, *B*) confirms that relative to his chin and nose, the lips are more prominent than most orthodontists would consider ideal. A reasonable orthodontic plan would involve four-premolar extraction to create space for retraction of the anterior teeth and reduction of dental protrusion and lip fullness over approximately a 2-year period. A plastic surgeon or oral and maxillofacial surgeon might be inclined to define this patient's profile as chin deficient and recommend chin augmentation. We refer to this as "diagnosis by procedure"—that is, "What I do is what you need."

As the consultation proceeded, the maturational soft tissue changes were discussed (i.e., expected nasal growth and profile flattening). The consultation was visually facilitated through the use of digital image projections, and the parents elected to forego extractions in favor of 1 year of nonextraction treatment to be followed by an advancement genioplasty at the appropriate age (Figure 2-20, *C–F*).

Much emphasis is now given to nonextraction treatment, but in cases of dental protrusion and an excessively full profile, extraction treatment still has a significant role. The patient in Figure 2-21, *A–C,* presented with congenitally missing maxillary lateral incisors and a large maxillary diastema. Facially, she exhibited excessive lip fullness and protrusion. Rather than close the diastema to make space for placement of lateral incisor implants, the treatment plan was to extract the mandibular first premolars, close the space in the maxillary arch to treat her with cuspid substitution, and retract the lower incisors resulting in protrusion reduction (Figure 2-21, *D–F*).

Effects on the Labiomental Sulcus. The labiomental sulcus is defined simply as the fold of soft tissue between the lower lip and the chin; it may vary greatly in form and depth. The sulcus is affected by facial height, overjet, and chin projection.

Orthodontists commonly see the effect of decreased vertical dentoskeletal relations on the labiomental sulcus because many orthodontic patients have short faces and Class II malocclusions. An exaggerated but excellent analogy of the effect decreased vertical dimension has on chin position is the edentulous patient who has removed his dentures before closing his mouth. The vertical overclosure causes tremendous loss in the vertical dimension, resulting in soft tissue redundancy of the lips expressed as a deep labiomental sulcus.

The adolescent patient in Figure 2-22, *A* and *B*, started treatment with 6 mm of overjet and a 53% lower facial height. Orthodontic treatment included cervical headgear for its orthopedic effect on the lower face and Class II anteroposterior correction. With the downward vector of force application, the posterior maxilla and maxillary

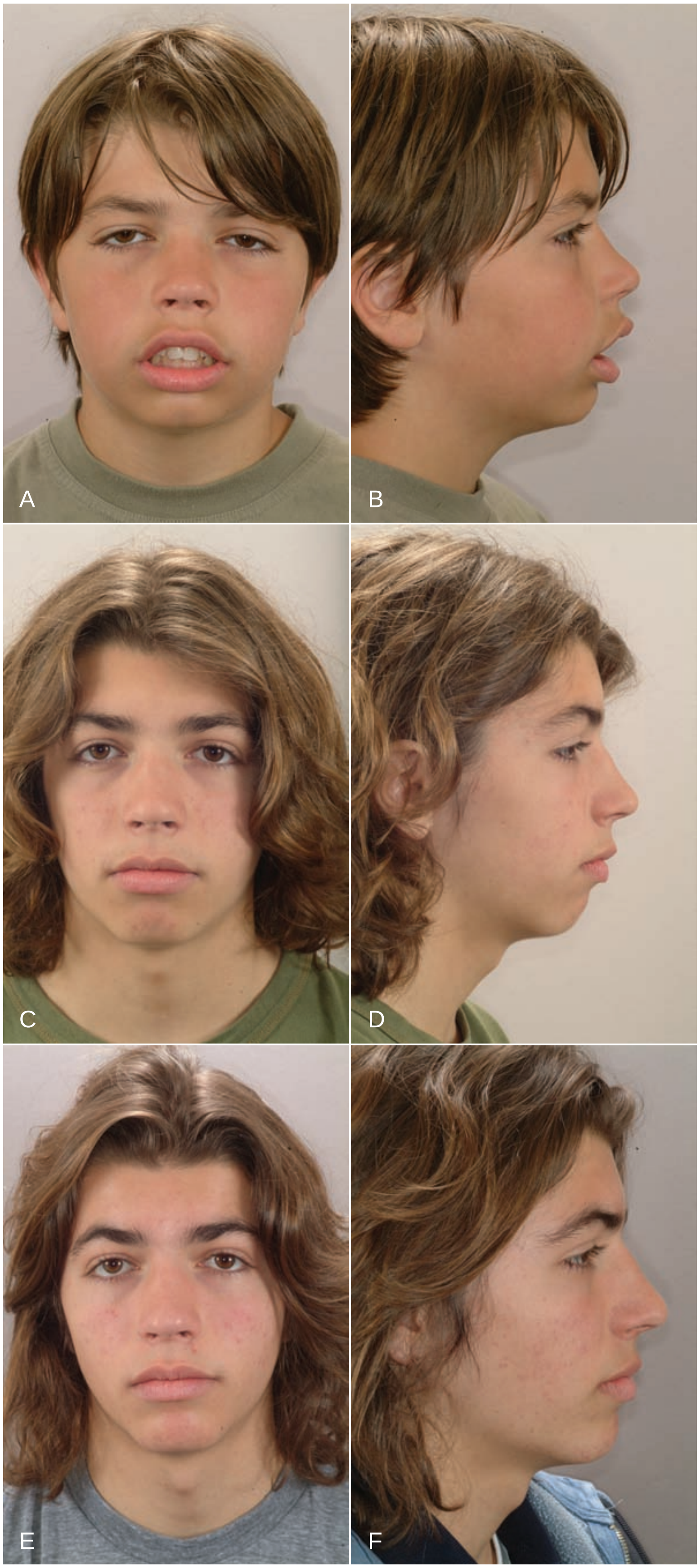


FIGURE 2-20 Because lip prominence is evaluated relative to the chin and nose, orthodontic retraction of anterior teeth or advancement genioplasty may yield a similar result. This patient presented with protrusive lips **(A),** and the profile **(B)** reflected lip fullness with chin deficiency. The patient was offered the option of orthodontic treatment to retract the anterior teeth but chose advancement genioplasty with nonextraction orthodontic treatment. Frontal **(C)** and profile **(D)** relationships are shown after completion of orthodontic treatment. The frontal **(E)** and profile **(F)** changes are shown after advancement of the chin. This case illustrates the nature of differential treatment choices in aesthetic treatment selection.

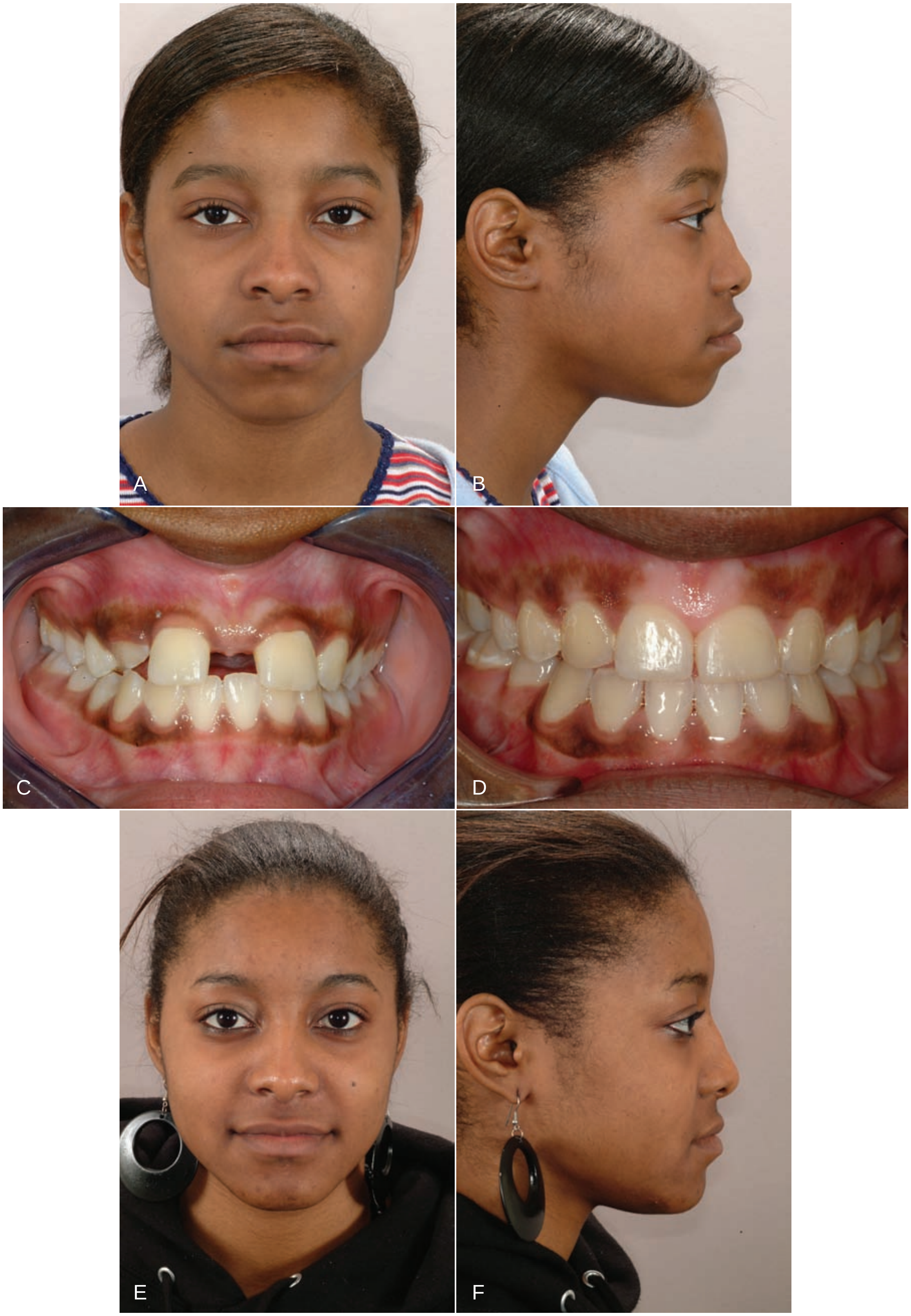


FIGURE 2-21 **A–C**, This adolescent patient presented with missing maxillary lateral incisors, dental protrusion, and lip protrusion. **D–F,** Protrusion reduction with lower first premolar extractions improved the balance of the lips and chin.

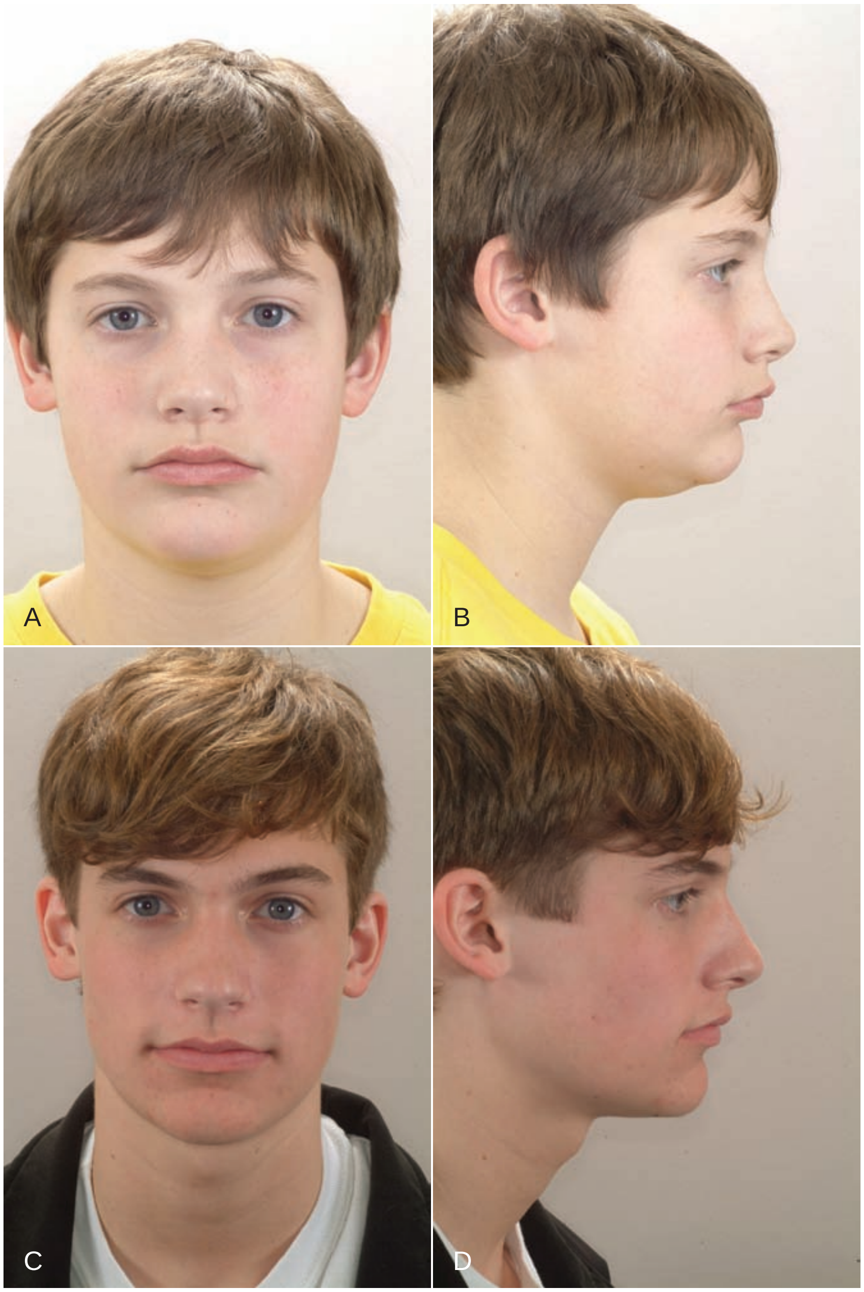


FIGURE 2-22 **A** and **B,** This growing patient had a Class II malocclusion, deep labiomental sulcus caused by overjet and diminished lower facial height resulting in lip redundancy. The recommended orthodontic treatment included cervical headgear and extrusive mechanics of the posterior teeth to reduce overjet while increasing lower facial height. **C** and **D,** The deep labiomental sulcus was improved through overjet reduction and increase in lower facial height.

dentition are extruded, thus increasing the lower facial height. Reverse-curve arch wire mechanics also were used with fixed appliances to extrude the mandibular posterior teeth and increase the lower facial height. The finished result Figure 2-22, *C* and *D*, shows the longer lower facial height and decrease in the depth of the labiomental fold achieved by growth and orthodontic and orthopedic treatment.

Chin Projection

Chin projection is determined by two factors: (1) the amount of anteroposterior bony projection of the anterior inferior border of the mandible and (2) the amount of soft tissue that overlays that bony projection. The combination of these two characteristics equals the total amount of chin projection.

NB-Pg is the cephalometric measurement most orthodontists refer to as "chin projection" and is quantified as the amount of bone projecting past the cephalometric NB line (a linear measurement in millimeters). Soft tissue thickness is also a variable in chin projection and has been studied extensively.[1]

Throat Form

Although throat form often is not considered in planning orthodontic treatment, it is an important aspect of facial aesthetics, and one must take into account the effect treatment has on it. An obtuse cervicomental angle often reflects the following:

- *Chin deficiency:* Chin deficiency results in slackening of the submental and platysmal musculature, resulting in an obtuse angle.
- *Lower lip procumbency:* Lower lip procumbency results in lip projection, which simply increases the obtuseness of the lip-chin-throat angle.
- *Excessive submental fat:* Excessive submental fat contributes to the bulk of the neck, increasing the lip-chin-throat angle.
- *Retropositioned mandible:* A retropositioned mandible also results in slackening of the submental musculature and results in an obtuse angle.
- *Low hyoid bone position:* Low hyoid bone position contributes to the obtuseness of the lip-chin-throat angle through its mechanical location and the attachment of the submental musculature.

Evaluation of the Smile (Miniaesthetics)

Importance of the Smile in Orthodontics. The subject of the smile and facial animation as it relates to communication and expression of emotion should greatly interest orthodontists. Although the English language is replete with words such as *smirk, insipid smile, wry smile, sardonic smile, ironic smile, inscrutable smile, infectious smile, warm smile,* and *enigmatic smile*, all of which conjure up specific images, these descriptions are entirely subjective. An attractive smile helps win elections, and a beautiful smile sells products for companies whose subliminal message in advertisement is "look better, feel younger." A "well-treated" orthodontic case in which plaster casts meet every criterion of the American Board of Orthodontics for successful treatment may not produce an aesthetic smile.

Interestingly, few objective criteria exist for assessing attributes of the smile, establishing lip–teeth relationship objectives of treatment, and measuring the outcomes of therapy. Without morphometric data for smile characteristics, orthodontists have no choice but to be entirely subjective in assessing smiles. Subjectivity can be reduced, however, by incorporating the measurements described below into the clinical examination.

Analysis of the Smile. The perception of dentofacial aesthetics by orthodontists and patients has differed considerably. An unposed smile is involuntary (i.e., not obligatory) and is induced by joy or mirth. A smile is dynamic in the sense that it bursts forth but is not sustained. All the muscles of facial expression are recruited in the process, causing a pronounced deepening of the nasolabial folds and squinting of the eyes. A nonposed smile (Figure 2-23, *A*) is natural in the sense that it expresses authentic human emotion. A posed smile (Figure 2-23, *B*), by contrast, is voluntary and need not be elicited or accompanied by emotion. Such a smile can be a learned greeting, a signal of appeasement, or an attempt to indicate self-assurance.

A posed smile is static in the sense that it can be sustained. If the smile is typical for a particular individual, a posed smile is natural, but the smile also can be "forced" to mimic a nonposed smile. In the latter circumstance, the smile cannot be sustained and will seem to be strained and unnatural. In the Peck classification, a Stage II smile is a "forced" or strained posed smile resulting in maximal upper lip elevation. Thus, two types of posed smiles are possible: strained

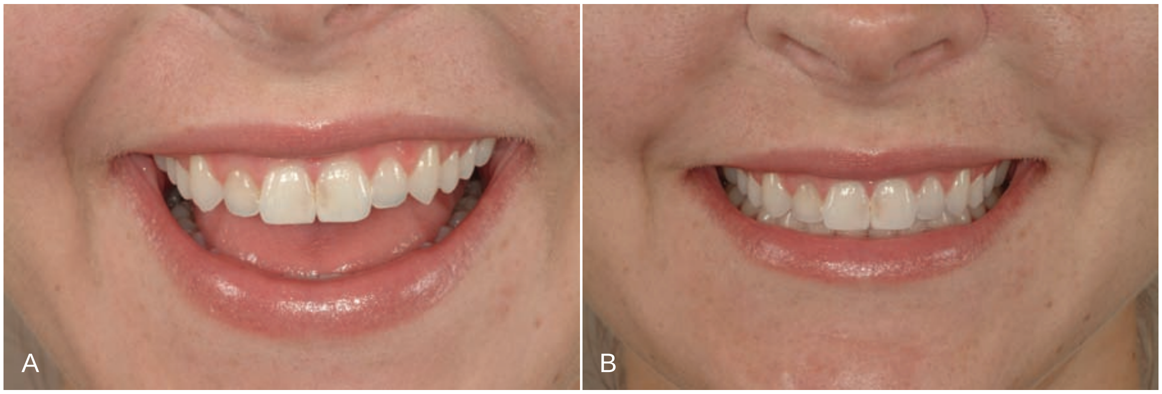


FIGURE 2-23 **A,** The nonposed smile is natural in the sense that it expresses authentic human emotion. **B,** A posed smile is voluntary and is static in the sense that it can be sustained.

and unstrained. When a person is asked to pose for a photograph, the smile that is desired is a voluntary, unstrained, static, yet natural smile. Hulsey[9] and Rigsbee et al.[10] agree that reproducibility of the posed smile is good.

In a 2½-year period of observation during adolescence, the changes in smile characteristics in untreated patients and in patients undergoing orthodontic treatment were remarkably small. If the conventional thinking that lip–tooth relationships change over time is correct, these changes must occur gradually or much later in life. These changes are likely a part of aging, rather than part of growth and development.

Diagnostic Smile Analysis: Measurement of Characteristics. Direct measurement permits the clinician to quantify the resting and dynamic tooth–lip relationships. Observation of the smile is a good start, but quantification of resting and dynamic tooth–lip relationships is critical to smile visualization so that the information gathered in the measurement of smile characteristics then can be translated into terms meaningful to the treatment plan. Systematic measurement of resting tooth–lip relationships and how the dynamics of the smile also interact with the maxillary teeth affect the appearance of the smile virtually leads the clinician to a quantified treatment plan.

The following frontal measurements at rest should be performed systematically:

- *Philtrum height* (Figure 2-24, *A*). The philtrum height is measured in millimeters from subspinale (the base of the nose at the midline) to the most inferior portion of the upper lip on the vermilion tip beneath the philtral columns. The absolute linear measurement is not particularly important, but what is significant is its relationship to the upper incisor and the commissures of the mouth.
- Commissure height. The commissure height (Figure 2-24, *B*) is measured from a line constructed from the alar bases through the subspinale and then from the commissures perpendicular to this line. The difference between philtrum height and commissure height decreases from adolescence to adult life. In adults in whom philtrum height remains considerably shorter than commissure height, the effect is an unwitting frown, so that the individual tends to look angry all the time regardless of whether he or she is angry. This effect can be improved with surgical lengthening of the philtrum.[11]
- *Interlabial gap*. The interlabial gap is the distance in millimeters between the upper and lower lips. An interlabial gap of greater than 4 mm is outside the normal range and is considered lip incompetence.
- *Amount of incisor display at rest* (Figure 2-24, *C*). The amount of upper incisor display at rest is a critical aesthetic parameter because one of the inevitable characteristics of aging is diminished upper incisor display at rest and on smile. As patients get older, the amount of incisor at rest decreases with age, as does the amount of tooth display on smile. The clinician must be aware of this because the effect of diminishing incisor display results in hastening the aging process in terms of smile appearance. For this reason, in orthodontic treatment the choice to open a deep bite with upper incisor intrusion may correct the occlusion at the cost of making the patient look significantly older.

Measurements on smile are as follows:

- *Amount of incisor display on smile* (Figure 2-24, *D*). On smile, patients will show either their entire upper incisor or only a percentage of the incisor or gingival display. Therefore, the number of millimeters of crown display on smile is recorded, and this may include the entire crown or, in cases of incomplete incisor display on smile, the amount of incisor shown.
- *Crown height and width*. The vertical height of the maxillary central incisors in the adult is measured in millimeters and is normally between 9 and 12 mm, with an average of 10.6 mm in men and 9.6 mm in women. The age of the patient is a factor in crown height because of the rate of apical migration in the adolescent. The width is a critical part of smile display in that the proportion of the teeth to each other is an important factor in the smile. Most references specify the central incisors to have about an 8 : 10 width-to-height ratio.
- *Gingival display.* The aesthetically acceptable amount of gingival display on smile varies, but one must always remember the relationship between gingival display and the amount of incisor shown at rest. In broad terms, treating a patient less aggressively in reducing smile gumminess is better when considering that the aging process will result in a natural diminishment of this characteristic. A gummy smile is often more aesthetic than a smile with diminished tooth display.
- *Smile arc*. The smile arc is defined as the relationship of the curvature of the incisal edges of the maxillary incisors and canines to the curvature of the lower lip in the posed social smile. The ideal smile arc has the maxillary incisal edge curvature parallel to the curvature of the lower lip on smile, and the term consonant is used to describe this parallel relationship (Figure 2-24, *E*). Nonconsonant or flat smile arc is characterized by the maxillary incisal curvature being flatter than the curvature of the lower lip on smile. The smile arc relationship is not as quantitatively measurable as the other attributes, so the smile arc is noted merely as consonant, flat, or reversed.

In treating the smile, the social smile in most cases represents a repeatable smile. An important note, however,

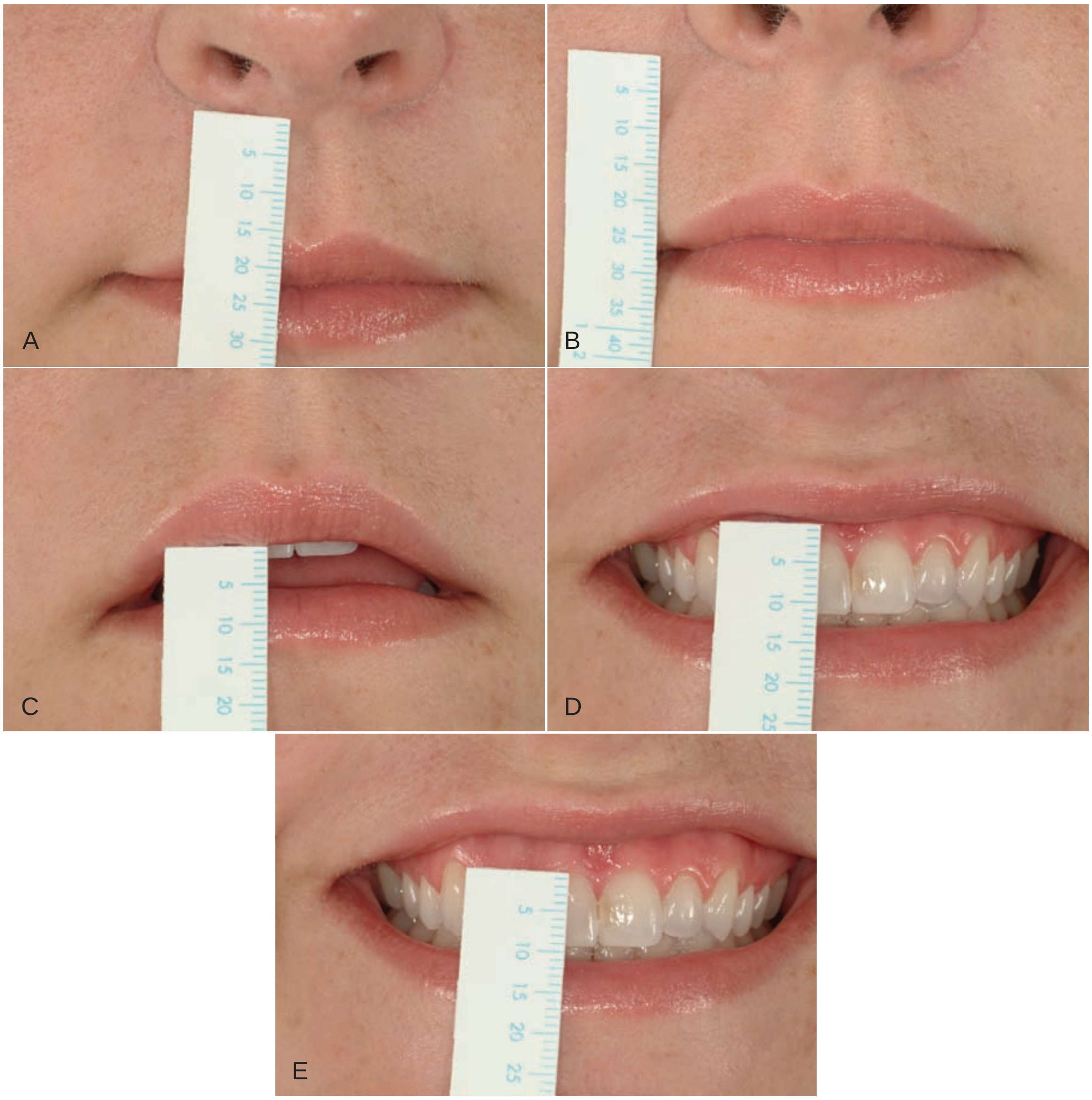


FIGURE 2-24 **A,** Philtrum height is measured from the base of the nose to the most inferior portion of the upper lip. **B,** Commissure height is measured from the alar base to the outer commissure of the lips. **C,** Incisor display at rest is an important measurement because it reflects the "relative age" of the patient. **D,** Incisor display and gingival display are recorded within the framework of the smile. In cases of incomplete incisor display on smile, the amount of incisor displayed is measured. In this same patient, crown height is also recorded because the entire crown is visible on smile. **E,** The smile arc, defined as the relationship of the curvature of the incisal edges of the maxillary teeth to the curvature of the lower lip, is evaluated in the posed social smile.

is that a "maturation" of the social smile may occur in many patients, and the smile may not be consistent from time to time in specific patients.

The authors have chosen the social smile as the representation from which to analyze the smile in four dimensions: frontal, oblique, sagittal, and time-specific.

Vertical Characteristics of the Smile. The vertical characteristics of the smile are categorized broadly into two main features: those pertaining to incisor display and those pertaining to gingival display. The patient shows the entire tooth or does not and shows the gingiva or does not. Inadequate incisor display can be a combination of vertical maxillary deficiency, limited lip mobility, and short clinical crown height. If short clinical crown height is the primary contributor to the inadequate tooth display, one must differentiate between a lack of tooth eruption (which may take care of itself as a child gets older), gingival encroachment (treated with crown lengthening), and short incisors secondary to attrition, treated by restorative dentistry with laminates or composite buildups (Figure 2-25).

Another feature of vertical smile characteristics is the relationship between the gingival margins of the maxillary incisors and the upper lip. The gingival margins of

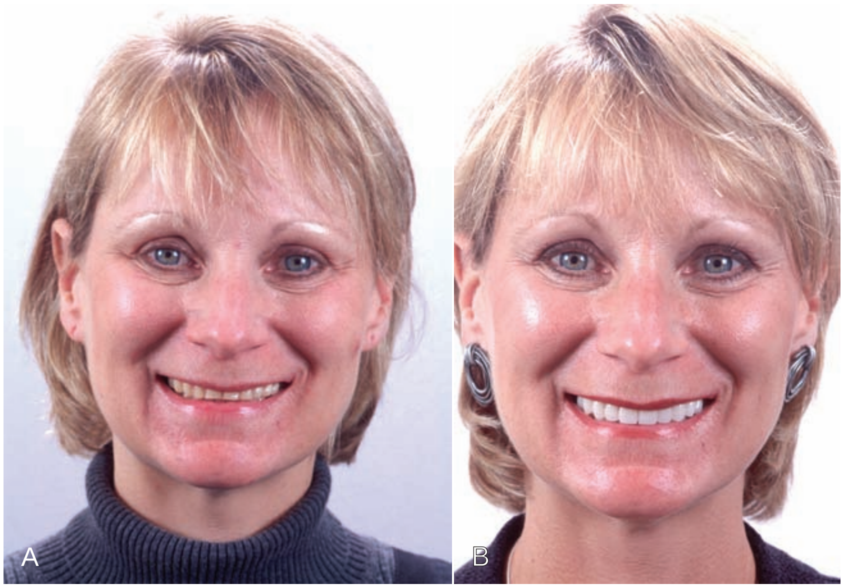


FIGURE 2-25 A flat smile arc can be caused by attrition of the maxillary incisors. **A,** This patient sought orthodontic consultation for smile improvement and was counseled that her problem was less of an orthodontic problem and more of a restorative problem. **B,** After laminate veneers were placed, incisal height and smile arc were restored.

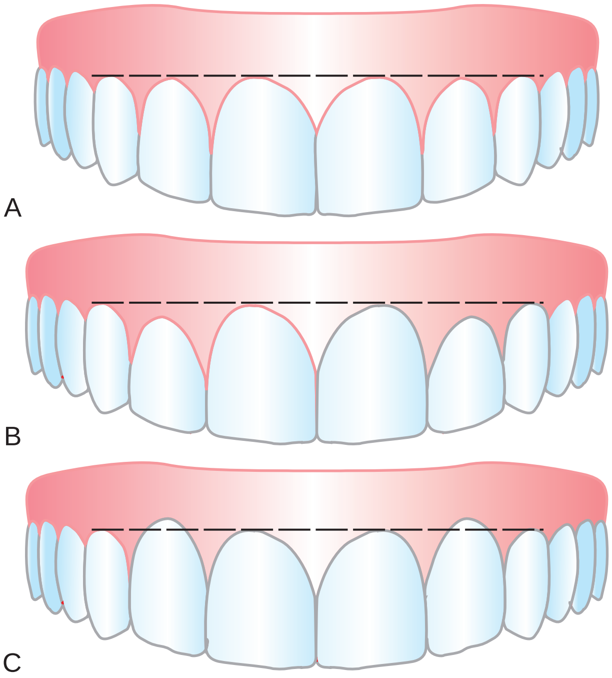


FIGURE 2-26 The gingival margins of the canines should be coincident with the upper lip, and the lateral incisors should be positioned slightly inferior to the adjacent teeth. **A,** Equal gingival height is acceptable. **B,** Ideal gingival height relationship. **C,** Least desirable gingival height relationship.

the canines should be coincident with the upper lip, and the lateral incisors should be positioned slightly inferior to the adjacent teeth (Figure 2-26). That the gingival margins should be coincident with the upper lip in the social smile is generally accepted. However, this is very much a function of the age of the patient because children show more tooth at rest and gingival display on smile than do adults.

Transverse Characteristics of the Smile. Three important influences on the characteristics of the smile in the transverse plane of space are (1) buccal corridor width,[12] (2) arch form, and (3) the transverse cant of the maxillary occlusal plane.

Buccal Corridor Width. This consideration was introduced into dentistry by the removable prosthodontics of the late 1950s. When setting denture teeth, prosthodontists sought to recreate a natural dental presentation transversely. A “molar-to-molar” smile was seen as fake and a tip-off to a poorly constructed denture. More recently, orthodontists have emphasized the diminished aesthetics of an excessively wide buccal corridor, often referred to as “negative space.” In orthodontics as in prosthodontics, the proportional relationship between the width of the dental arch and the width of the face must be kept in mind.

The buccal corridor is measured from the mesial line angle of the maxillary first premolars to the interior portion of the commissure of the lips. The corridor often is represented by a ratio of the intercommissure width divided by the distance from the first premolar to first premolar.

Arch Form. Arch form plays a pivotal role in the transverse dimension of the smile. In patients whose arch forms are narrow or collapsed, the smile also may appear narrow, which is less appealing aesthetically. An important consideration in widening a narrow arch form, particularly in the adult, is the axial inclination of the buccal segments. Patients in whom the posterior teeth are already flared laterally are not good candidates for dental expansion. Patients in whom the premolars and molars are upright have more capacity for transverse expansion in adolescence, but the characteristic is particularly important in the adult in whom sutural expansion is less likely.

Orthodontic expansion and widening of collapsed arch form can improve the appearance of the smile dramatically by decreasing the size of the buccal corridors and improving the transverse smile dimension (Figure 2-27). The transverse smile dimension (and the buccal corridor width) is related to the lateral projection of the premolars and the molars into the buccal corridors. The wider the arch form in the premolar area, the greater is the amount of the buccal corridor that is filled.

Expansion of the arch form may fill out the transverse dimension of the smile, but two undesirable side effects may result, and one should take care to avoid them. First, excessive expansion obliterates the buccal corridor. Prosthodontists emphasize that this is unaesthetic. Second, when the anterior sweep of the maxillary arch is broadened (Figure 2-28), the prominence of the incisors relative to the canines is likely to decrease. When these undesirable aspects of expansion are being considered, the clinician must make a judgment in concert with the patient as to what tradeoffs are acceptable in the pursuit of the ideal smile.

When the maxilla is retrusive, the wider portion of the dental arch is positioned more posteriorly relative to the anterior oral commissure. This creates the illusion of greater buccal corridor in the frontal dimension. The patient in Figure 2-29 had a Class III malocclusion caused primarily by maxillary deficiency, vertically (characterized by only 50% of maxillary incisor show on smile) and anteroposteriorly (as evidenced by the flatness of the profile). After orthodontic decompensation the surgical plan was to advance the maxilla, rotating it clockwise to increase the amount of incisor display at rest and on smile. This occlusal plane rotation not only improves the incisal display but also increases midfacial projection and diminishes mandibular projection. The smile was enhanced greatly by the increased vertical anterior tooth display, but the transverse smile dimension also was improved greatly (Figure 2-29, *B*). How was the negative space on smile reduced when there was no maxillary expansion? As the maxilla came forward into the buccal corridor, the negative space was reduced by the wider portion of the maxilla coming forward into the static intercommissure width. Transverse smile dimension, therefore, is a function of arch width and anteroposterior position of the maxillary and mandibular arches.

Transverse Cant. The last transverse characteristic of the smile is the transverse cant of the maxillary occlusal plane. A canted or asymmetric smile can be a result of (1) asymmetric vertical growth of the mandible resulting in a compensatory cant to the maxilla, (2) lip curtain asymmetry, or (3) differential gingival heights. A true transverse cant usually is related to asymmetric vertical growth of the mandible resulting in a compensatory cant to the maxilla and, if present, may be an indication for orthognathic surgery. The appearance of a transverse cant, however, can result from differential eruption and placement of the anterior teeth or differential anterior crown heights requiring soft tissue modification, both of which should be considered in planning orthodontic treatment. Neither intraoral images nor mounted dental casts adequately reflect the relationship of the maxilla to the smile (Figure 2-30). Only frontal smile visualization permits the orthodontist to visualize any tooth-related asymmetry transversely. The frontal smile photograph (Figure 2-30, *B*), not a frontal view of the teeth achieved with a lip retractor, is needed to record what is seen clinically. With good documentation of tooth–lip relationships, the orthodontist subsequently can make any appropriate adaptations in appliance placement or make a decision on the need for differential growth or dental eruption modification of the maxilla in the adolescent or surgical correction in the adult.

Smile asymmetry also may be due to asymmetric lip animation. A differential elevation of the upper lip during smile gives the illusion of a transverse cant to the maxilla. This characteristic emphasizes the importance of direct clinical examination of the smile because this soft tissue animation is documented poorly in static photographic images but is documented best in digital video clips. This can become an important informed consent issue if the patient is concerned about the asymmetry on animation because neither orthodontic tooth movement nor orthognathic surgery will affect it.

Oblique Characteristics of the Smile

The oblique view of the smile reveals characteristics not obtainable on the frontal view and certainly not obtainable through any cephalometric analysis. The contour of the maxillary occlusal plane from premolar to premolar should be consonant with the curvature of the lower lip on smile (a view of the smile arc, discussed previously). Deviations include a downward cant of the posterior maxilla, upward cant of the anterior maxilla, or variations of both. Figure 2-31 illustrates a patient in preparation for maxillary surgery to close an anterior open bite. Deciding how much the posterior maxilla should be impacted versus the anterior maxilla coming down depends on the amount of incisor display at rest and on smile and on the smile arc relationship, both of which are well visualized in the oblique view.

The amount of incisor proclination also can have dramatic effects on incisor display. In simple terms, flared maxillary incisors tend to reduce incisor display, and upright maxillary incisors tend to increase incisor display (Figure 2-32). A good example is the patient in Figure 2-33. This patient had an anterior open bite

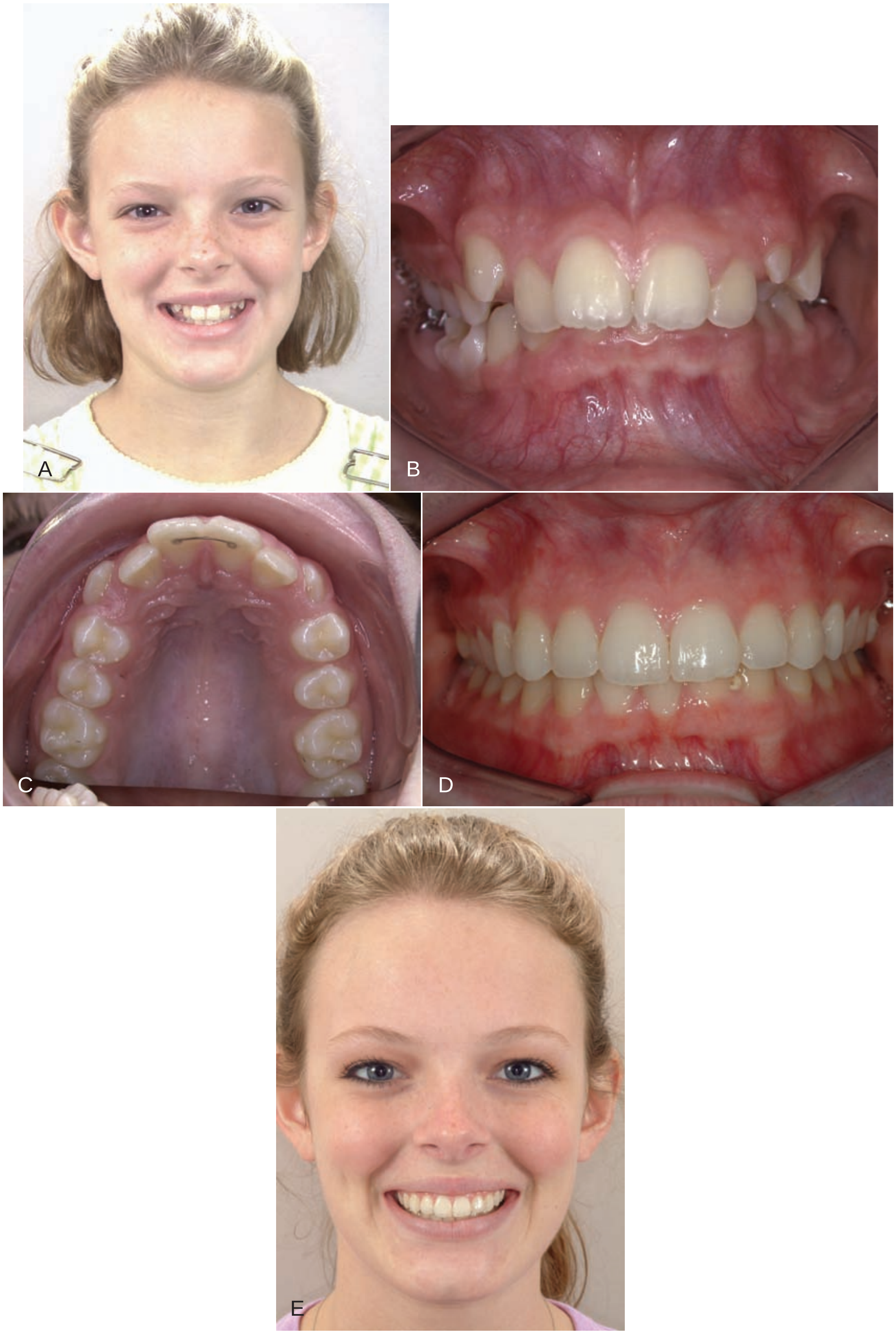


FIGURE 2-27 **A,** This adolescent patient has excessive buccal corridor width or negative space on smile. **B** and **C,** The intraoral views demonstrate the transverse deficiency of the maxilla. **D,** After orthodontic correction of the malocclusion, including orthodontic expansion, the transverse smile dimension is dramatically improved with projection of the teeth into the buccal corridor **(E).**

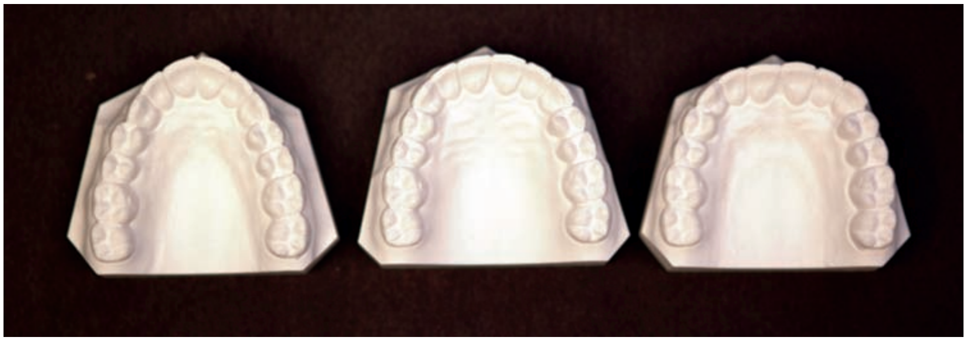


FIGURE 2-28 When the anterior sweep of the maxillary arch is broadened, the prominence of the incisors relative to the canines is likely to decrease, and flattening of the smile arc may occur. The clinician must make a judgment in concert with the patient as to what tradeoffs are acceptable in the pursuit of the best possible smile.

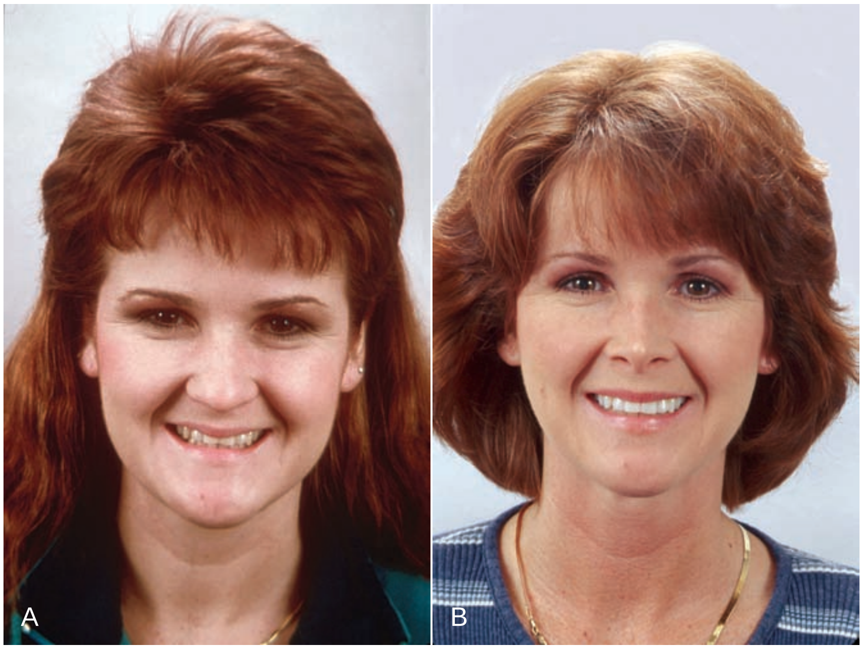


FIGURE 2-29 This patient exhibited a Class III malocclusion primarily caused by maxillary deficiency. **A,** Some aspects of vertical maxillary deficiency are present, including 50% of maxillary incisor display on smile. Her transverse smile dimension was characterized by excessive buccal corridors. **B,** Surgical maxillary advancement improved the buccal corridors on smile by bringing a wider portion of the maxilla forward into the buccal corridors, and bringing the maxilla down anteriorly resulted in increased incisor display.

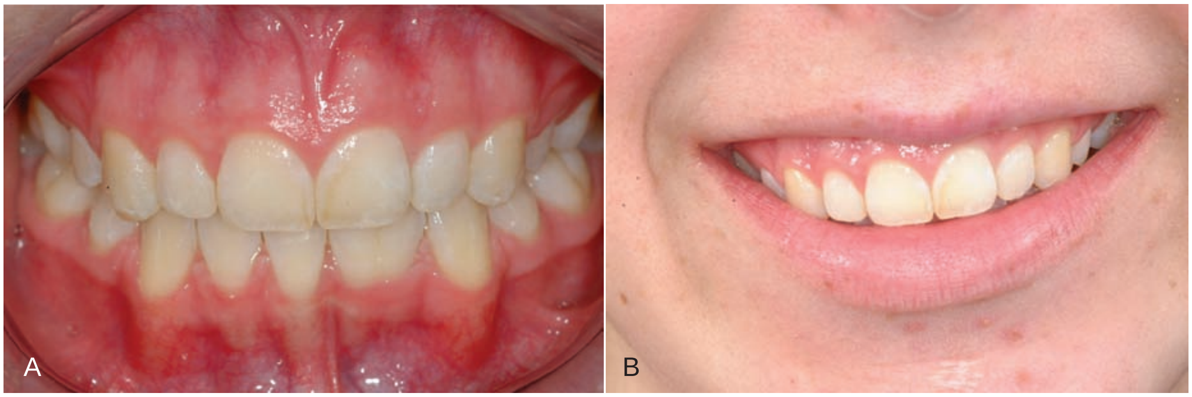


FIGURE 2-30 Neither intraoral images nor mounted casts adequately reflect the relationship of the incisors to the smile. In a close-up intraoral image **(A),** one sees an apparently well-treated occlusion, while a more distant smile view **(B)** reveals the same occlusal relationships with an obvious cant to the maxilla.

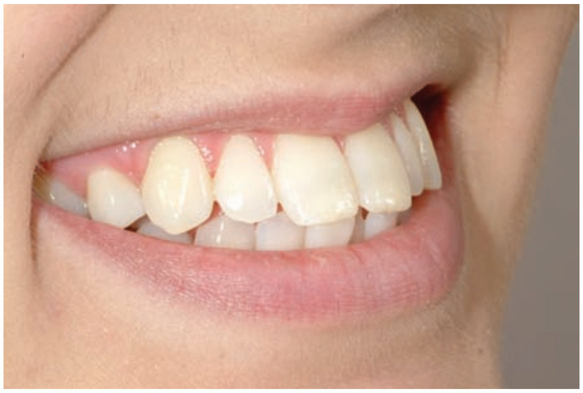


FIGURE 2-31 The close-up of the oblique smile, as in this patient in the last stages of preparation for orthognathic surgery to correct severe open bite, facilitates evaluation of the curvature of the molars (when visible), premolars, and anterior teeth in relation to the lower lip on smile. This also enhances closer evaluation of any anteroposterior cant to the palatal and occlusal planes.

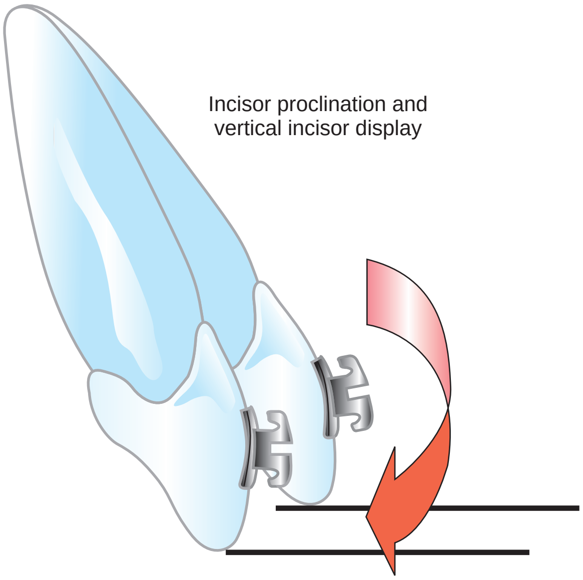


FIGURE 2-32 The amount of proclination of the maxillary incisors can affect how much they are displayed at rest and on smile. In general terms, flared maxillary incisors tend to reduce incisor display, and upright maxillary incisors tend to increase incisor display.

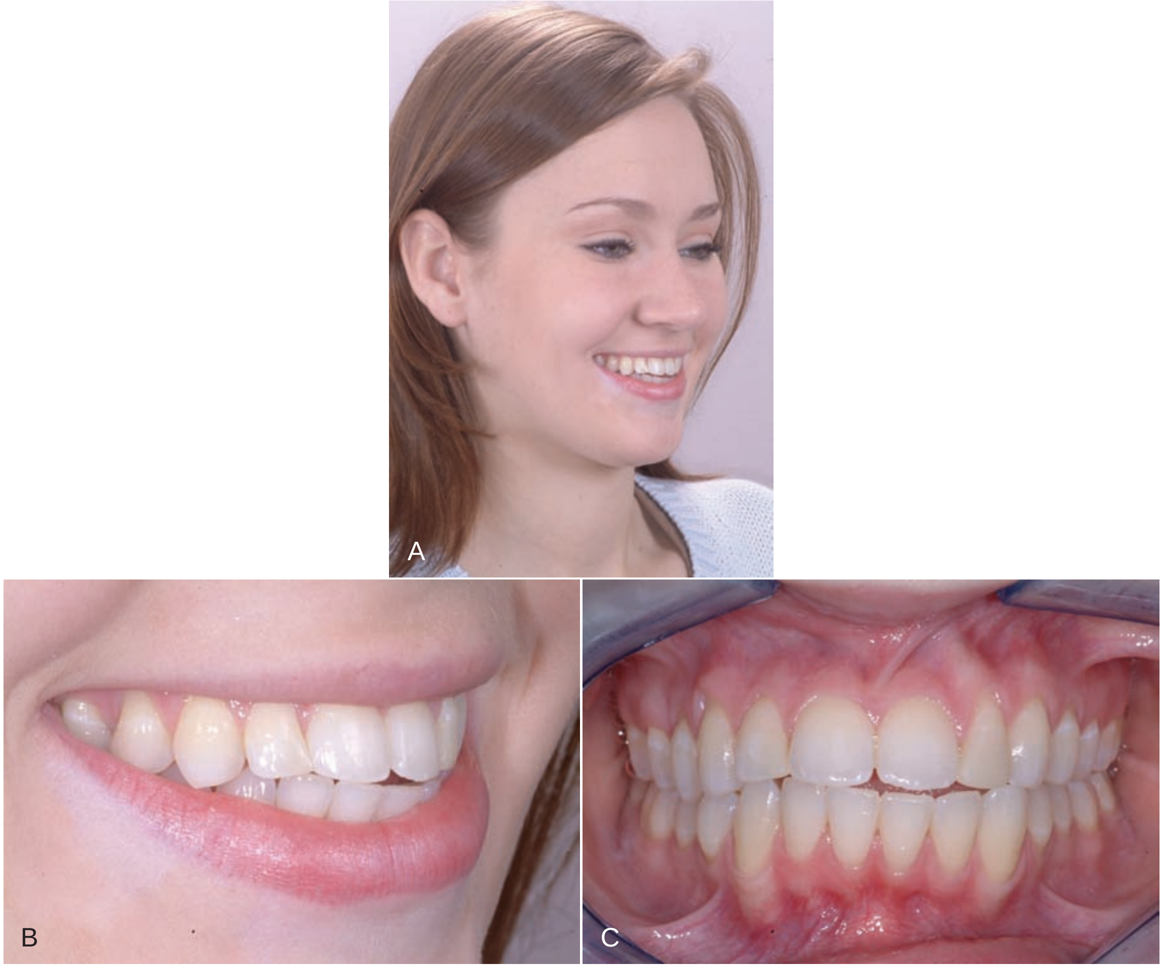


FIGURE 2-33 **A,** The frontal smile relationship demonstrates diminished incisor display on smile. **B,** On sagittal smile the flare and proclination of the upper incisors is apparent. **C,** After interproximal reduction and retraction and uprighting of the maxillary incisors, the amount of incisor display increased.

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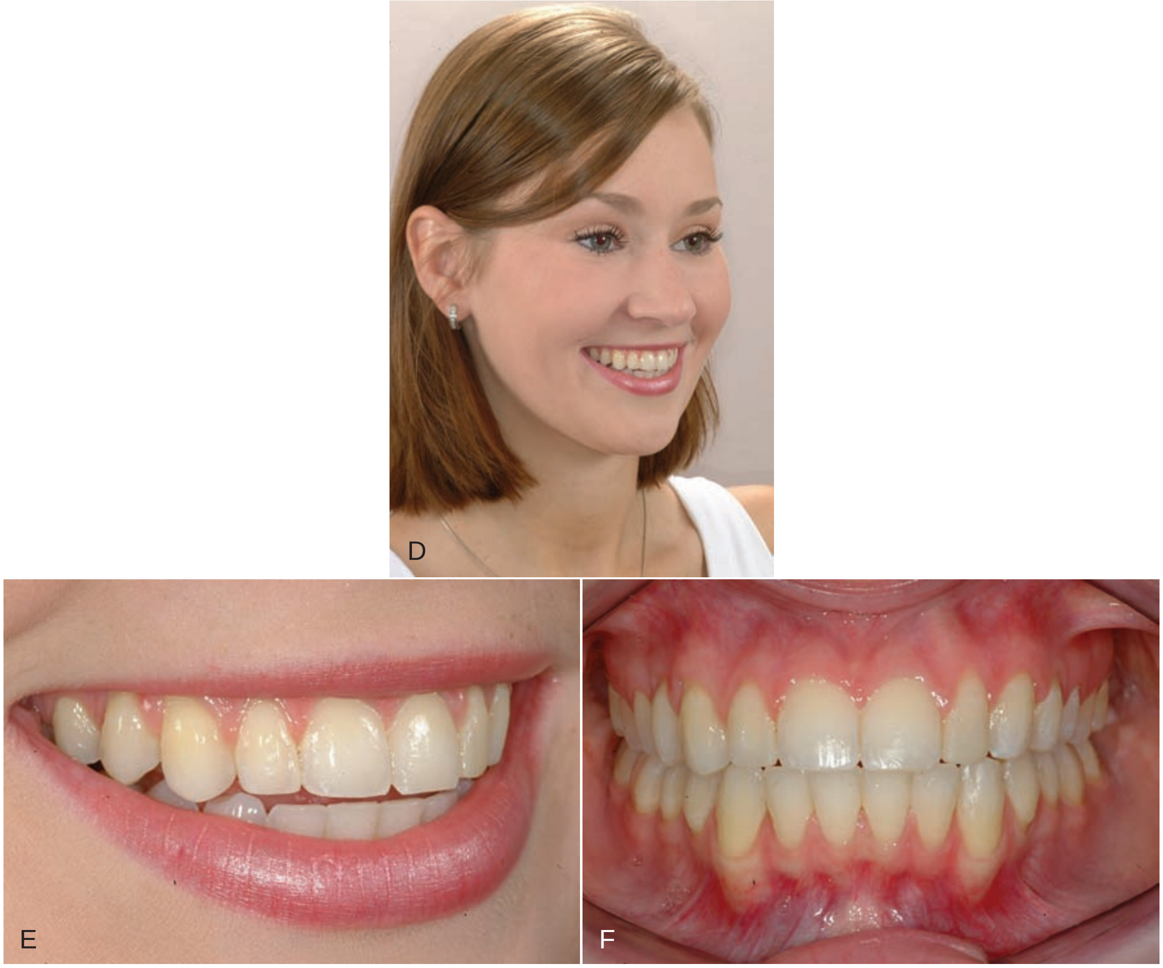

FIGURE 2-33, cont'd **D–F,** The sagittal smile image demonstrates the increased incisor display and the more aesthetic incisor angulation.

caused primarily by extreme anterior proclination of the maxillary and mandibular incisors. The sagittal view of the smile shows the flare of the maxillary incisors, which resulted in diminished incisor show from the frontal view. The treatment plan involved interproximal reduction of the incisors to provide space for retraction and uprighting of the incisors. The incisors were retracted in such a way to allow the crowns to tip distally so that they also elongated toward the occlusal plane. This movement closed the anterior open bite, increased incisor display as the teeth, and decreased the unaesthetic flare of the incisors.

Dental Microesthetics and Its Applications to the Smile

Gingival Shape and Contour. Important factors in finishing orthodontics cases for optimal smile aesthetics now include concepts that are important in cosmetic dentistry: gingival shape and contours, tooth proportionality, and crown heights.[13] Most orthodontists have reshaped incisal edges and tooth contours to refine the finish of treatment, but alteration of the gingival contours has been limited primarily to crown lengthening. Of the many concepts from cosmetic dentistry that are important to the microaesthetic smile appearance, two that are important for the final aesthetic outcome of orthodontic cases are gingival shape and gingival contour.[14]

According to the American Academy of Cosmetic Dentistry,[15] "the gingival shape of the mandibular incisors and the maxillary laterals should exhibit a symmetrical half-oval or half-circular shape. The maxillary centrals and canines should exhibit a gingival shape that is more elliptical. Thus, the gingival zenith (the most apical point of the gingival tissue) is located distal to the longitudinal axis of the maxillary centrals and canines. The gingival zenith of the maxillary laterals and mandibular incisors should coincide with their longitudinal axis" (see Figure 2-26).

Recontouring gingival shape and contour now can be accomplished readily, in the orthodontist's office if desired, with a diode laser.[3]

The patient in Figure 2-34, *A*, underwent orthodontic treatment as a child, achieving the occlusal goals desired, but her smile was characterized by moderately excessive gingival display because of short crown height. By age 18 (Figure 2-34, *B*), she was referred for aesthetic crown lengthening, and the procedure resulted in a remarkable smile improvement. However, after healing, some concern existed over the less than ideal gingival shape and contour. The gingival shape was not as elliptical as desired (Figure 2-34, *C*), and the gingival contour was characterized by rolled margins and large interdental papillae. As a secondary procedure, facilitated with topical anesthesia, the gingival margins were touched up with a soft tissue laser (Figure 2-34, *D*). The gingival shape of all the anterior teeth shape was contoured, resulting in superior gingival margin that was more rounded and elliptical, and with the zenith placed just distal to the long axis to the tooth. The interdental papilla was also debulked and contoured to sharper margins. After healing (Figure 2-34, *E*), the gingival contours were much improved.

When finishing the anterior aesthetic relationship within the smile framework, the average location of the gingival margins should demonstrate a symmetric level of the margins of the central incisors and a lower location of the lateral incisors and gain a higher and ideally symmetric level on the canines. The patient in Figure 2-35, *A*, was treated to an excellent occlusal and a good

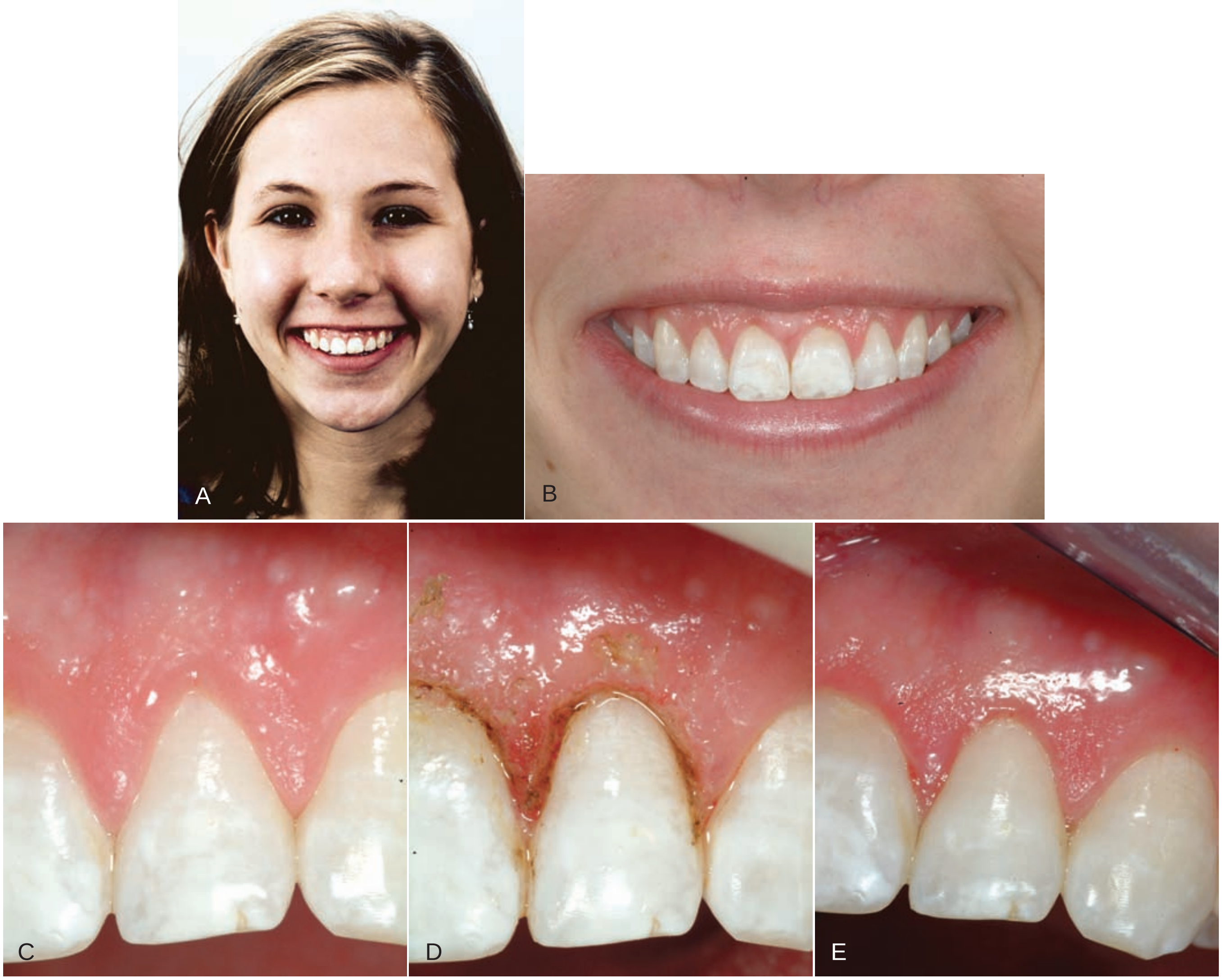

FIGURE 2-34 **A,** When this patient completed orthodontic treatment at age 14, her smile was characterized by moderate gingival display caused by short crown height. **B,** At age 18 the patient was referred for periodontal crown lengthening, with a great improvement in the smile. **C,** At that point, however, the gingival shape was not as elliptical as desired (as demonstrated in this lateral incisor), and the gingival contour was characterized by rolled margins and large interdental papillae. **D,** The gingival shape was contoured with a soft tissue laser, and the superior margin was more rounded and elliptical, with the zenith placed just distal to the long axis to the tooth. The interdental papilla also was debulked and contoured to sharper margins. **E,** After healing, the gingival contours were much improved.

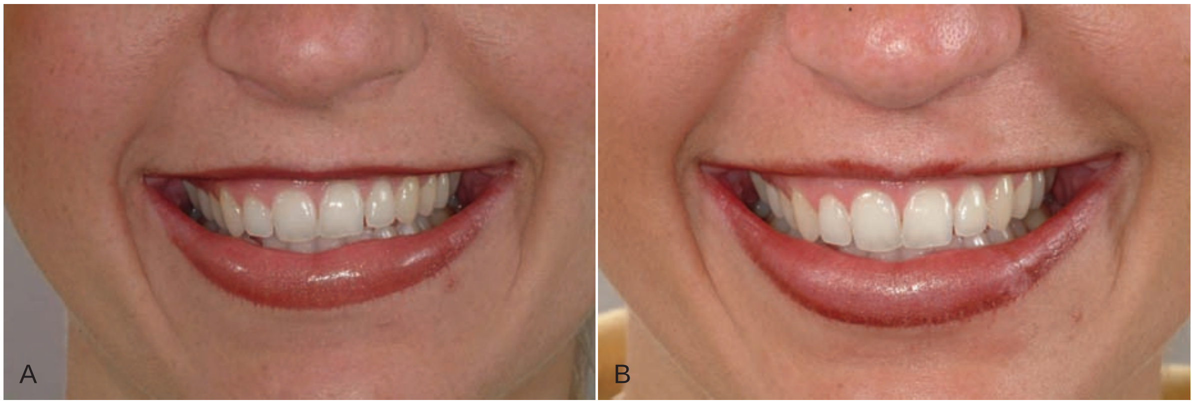

FIGURE 2-35 **A,** This patient's smile line was asymmetric because of differential crown heights. **B,** Three weeks after soft tissue contouring and lengthening of the right central and lateral incisors, the smile was more symmetric and greatly improved.

aesthetic result. However, the smile line was asymmetric because of differential crown heights of the maxillary right central and lateral incisors, relative to the left side. Using the diode laser, the excess gingiva was excised on the right central and lateral. Three weeks later, the smile was more symmetric and greatly improved (Figure 2-35, *B*).

Bracket Placement in Preparation for Changes in Gingival Shape. When a dentist is preparing teeth for laminates, it is not uncommon to reshape and idealize the gingival heights and contours with a soft tissue laser before final preparations are made and impressions are taken. In orthodontic treatment, because orthodontists usually are not able to make contour or shape adjustments, their recognition factors are low relative to these problems. Orthodontists must be able to visualize the crown in ideal proportion before bracket placement and in many cases shape and contour the gingiva prior to bracket placement.

The patient in Figure 2-36, *A*, has a disproportionate width-to-height ratio of the maxillary incisors. Most aesthetic dentists strive for a central incisor width-to-height proportion of 8 : 10, and this patient's incisors have the same width and height. This disproportion could be due to lack of incisor height (gingival encroachment or delayed or incomplete passive eruption requiring gingival reshaping) or incisors that are morphologically wider than ideal in terms of crown shape itself (requiring reshaping of the crown). Bracket placement in orthodontics has traditionally been directed by the relationship of the bracket slot to the incisal edge. Anterior teeth vary in crown height and incisal edge shape. The two most common current methods for placing brackets are to (1) relate the bracket position to the incisal edge or (2) position the bracket in the center of the clinical crown, whatever its dimensions. In this patient, positioning of the bracket a prescribed 4.5 mm from the incisal edge would place the bracket too close to the gingival margin, potentially causing gingival overgrowth and oral hygiene problems. Positioning of the bracket in the center of the clinical crown (Figure 2-36, *B*) would cause unwanted maxillary incisor intrusion and a reduction in incisor display on smile. In this case, the decision was to improve tooth proportion through laser crown lengthening before bracket placement to maximize the chance of positioning the incisors in their ideal vertical position (Figure 2-36, *C*).

Bracket Positioning for Optimal Aesthetics. As orthodontists diagnostically move away from the procrustean approach to diagnosis and treatment planning (every patient gets fitted to the same cephalometric analysis, and all patients have their brackets placed the same distance from the incisal edge or cusp tip, according to a chart), concepts of bracket placement also are evolving. Rather than bracket placement being a function of the dental-centric preadjusted appliance demands, placement of the maxillary and mandibular anterior teeth should be directed by concerns such as the following:

1. How much maxillary incisor is displayed at rest (recall the data on incisor display at rest and the aging smile)
2. How much maxillary incisor is displayed on smile (also a characteristic of the youthfulness of the smile)
3. The relationship of the anterior teeth to the smile arc
4. Crown height and width incisor proportionality
5. Gingival height and contour characteristics

What is the process to determine the desired bracket placement for each individual patient? As in the macroaesthetic and miniesthetic treatment goal setting, a systematic approach to these microaesthetic considerations

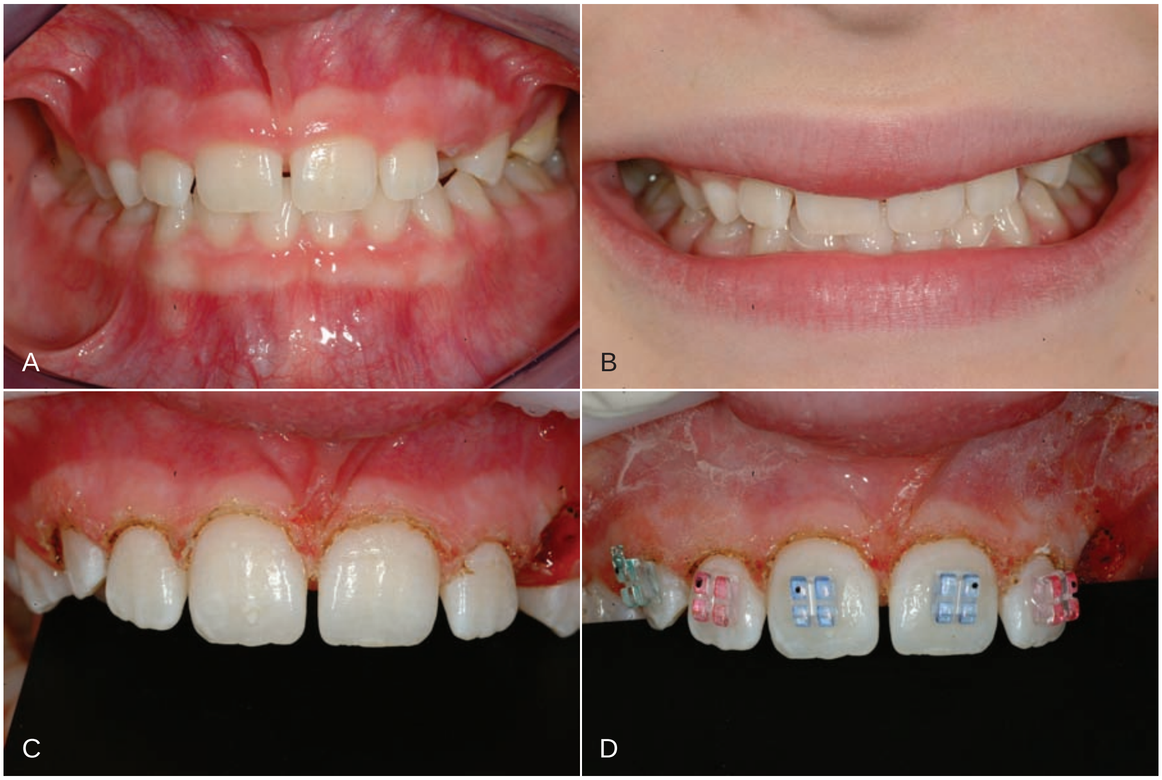

FIGURE 2-36 **A,** This patient has a disproportionality of the width and height of the maxillary incisors. The short crown heights were due to incomplete passive eruption. Positioning the brackets relative to the incisal edge would position them too close to the gingival margin, which would contribute to poor oral hygiene and result in gingival overgrowth. Positioning the brackets in the center of the clinical crown would cause unwanted incisor intrusion (**B**) in a patient where this was not desired. **C,** The decision was made to improve tooth proportion through laser crown lengthening before bracket placement to maximize the chance of positioning the incisors in their ideal vertical position. **D,** Immediately after bracket placement.

is needed. The authors recommended the following sequence of measurements to be made on the initial examination, recorded in the database program. To determine optimal bracket placement:

1. Determine the incisor display at rest (Figure 2-37, *A*):
   a. Refer to the chart of incisor display related to age for a guideline as to appropriate incisor display at rest (Figure 2-37, *B*)
2. Determine how much maxillary incisor is displayed on smile in millimeters (Figure 2-37, *C*)
3. Determine crown height and width of the incisors. This helps establish whether tooth shape discrepancies exist. If the tooth is too wide, tooth reduction may be desirable before bracket placement. If the incisor is short because of delayed passive eruption or gingival encroachment, crown lengthening may be indicated.
4. Note the number of millimeters of gingival display on smile if present.
5. Refer to chart of gingival display by age (see Figure 2-37, *C*).
6. Determine the smile arc–consonance relationship.
7. Measure gingival height relationships.
   a. Canine–lateral–centrals
   b. Canine–lateral–centrals to upper lip on repeatable social smile
8. Make final decisions and establish applications. For example, if incisor display at rest and on smile is inadequate, then do the following:
   a. Decide how much more tooth display is desired at rest or on smile and how far the incisal edge needs to go to reach the smile arc.
   b. Measure to the center of the clinical crown where most bracket systems require placement.
   c. Place the bracket more apically the distance the incisor is to be moved inferiorly.

The application of this approach to bracket placement is illustrated next.

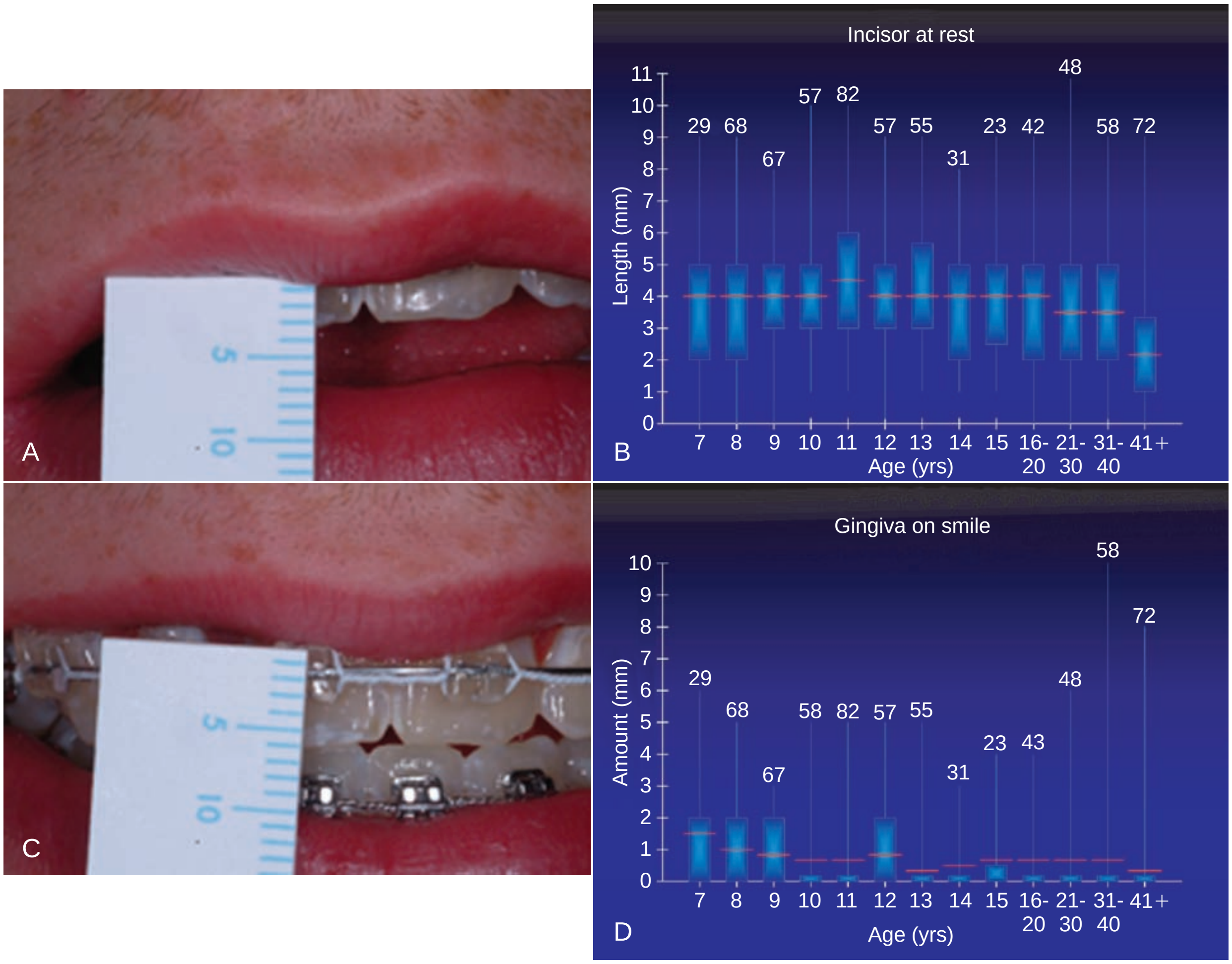

FIGURE 2-37 **A,** The first step in individualizing bracket placement is to determine how much maxillary incisor shows at rest. The purpose of this measurement is to place the incisor in the best position for smile display and to anticipate the long-term effects of aging. **B,** Refer to the chart for appropriate amounts of incisor display for the patient in a particular age group who is to receive brackets. The clinician should consider that these data represent an untreated population, and if smile youthfulness is desired, then greater incisor display may be planned in certain cases. **C,** Next, the orthodontist asks the patient to smile (social smile) and makes a direct measurement of how much upper incisor shows on smile. **D,** The amount of gingival display is measured when present and is compared against the chart for gingival display and to the crown height measurement. If gingival display on smile is excessive, the clinician can determine whether it is caused by vertical maxillary excess or short crown height.

CASE STUDY 2-1

SMILE REFINEMENT

Miniaesthetics and Microaesthetics

David M. Sarver, DMD MS

In cosmetic dentistry, tooth shape and proportions have been studied extensively. In addition to the height and width proportions, the concepts of tooth contacts and "connectors" can be of real significance in treatment planning the appearance of the smile. Contacts are defined as the exact place that the teeth touch (what makes floss snap) and the connector is where the incisors and canines "appear" to touch. Figure 2-38, *A* and *B*, illustrates the desired relationship of embrasures, contacts, and connectors.

This 40-year-old woman (Figure 2-39, *A*) sought orthodontic consultation for "an improved smile." She had normal skeletal relationships, and the negative aspects of her smile were incomplete incisor display on smile and a flat smile arc (Figure 2-39, *B*). Her occlusal relationships were also normal, but her tooth shape was disproportionate. Her maxillary incisors were square-looking and not as attractive as they could be, specifically the following:

1. The central incisors were disproportionate in height to width. The maxillary right central had a 1:1 height-to-width ratio, and the left central incisor ratio was 9:10 (Figure 2-39, *C*).
2. The connectors were also disproportionate, with the connector length between the centrals being only 20%, 50% between the central and lateral, and about 50% between the lateral and canine (Figure 2-39, *D*).
3. A tooth size discrepancy existed with slight overjet caused by maxillary excess.
4. The gingival shape was also not elliptical, and the zeniths were located inappropriately.

To improve her smile and increase its youthfulness, incisor extrusion would be required to increase incisor display. A recommendation of laminate veneers to deal with the tooth proportionality problem would have been possible, but because the tooth size discrepancy was present, tooth reshaping was thought to be the best method to improve the appearance of her teeth.

The decision to narrow the teeth to attain more desirable tooth proportionality was based on two factors:

1. The tooth size discrepancy with overjet permits retraction of the teeth against the lower incisors.
2. The contacts and connectors required adjustment as well.

An imaging session was performed to help the patient visualize the extrusion of the maxillary anterior teeth and its improvement on the smile arc (Figure 2-39, *E*).

When orthodontic treatment was begun, the maxillary incisor brackets were placed more superiorly than the posterior brackets so that the maxillary incisors were extruded. Once leveling was achieved, an air rotor stripping bur was used to break the contracts between the incisors and reshape the mesiodistal width of the teeth so that the connectors were lengthened between the central incisors and normalized further posteriorly. After reshaping of the mesial and distal widths of the incisors to obtain a better height-to-width ratio and improve the height of connectors, the gingival shape and contour were assessed. The authors noted that relative to the long axis of the maxillary central incisors, the zenith on the maxillary right central was placed too far distally and the gingival margin was lower than the left central, even with the right lateral. The left central incisor had its zenith placed mesial to the long axis of the tooth. At the end of treatment, a soft tissue laser was used to lengthen the right central incisor and relocate the zenith more appropriately to the long axis of the tooth. The spaces between the teeth were closed, and the embrasures were shaped by a diamond-shaped bur. Finally, a soft tissue laser was used to lengthen the right central incisor and relocate the central zeniths more appropriately (Figure 2-39, *F* and *G*).

The final smile is depicted in Figure 2-40 intraoral images. This case illustrates the cosmetic trends in orthodontics in terms of achieving occlusal goals, but aesthetic ones as well. Orthodontists traditionally have thought of reshaping incisal edges, but with refinement of cosmetic dental thinking, for orthodontists also to think of tooth shape and proportionality as part of the treatment planning and goal setting is not unreasonable.

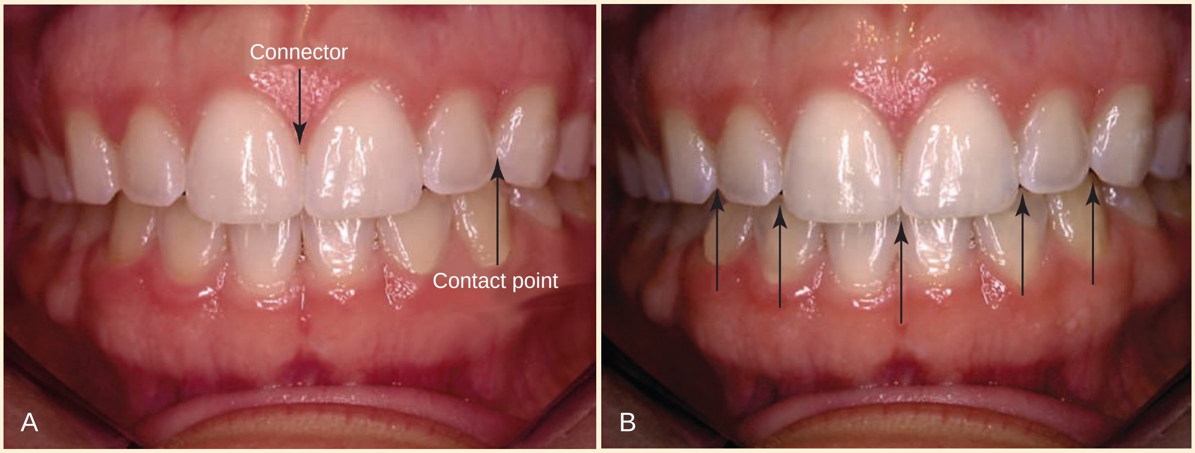

FIGURE 2-38 **A,** This illustration demonstrates the principles of cosmetic dentistry in terms of tooth and gingival shape and proportions. The contact point is where the teeth actually touch (and makes the floss snap when flossing). The connector is where the anterior teeth appear to touch. The desired ratio of connector to incisor height is for the connector height between the maxillary centrals to be 50% of maxillary central incisor height. Between the maxillary centrals and laterals, the connector should be 40% of the maxillary central incisor height. The connector length between the lateral and the cuspid should be 30% of central incisor height. **B,** The embrasures (the triangular space incisal to the contact) should progress in size from the central incisors posteriorly.

Continued

CASE STUDY 2-1

SMILE REFINEMENT—cont'd

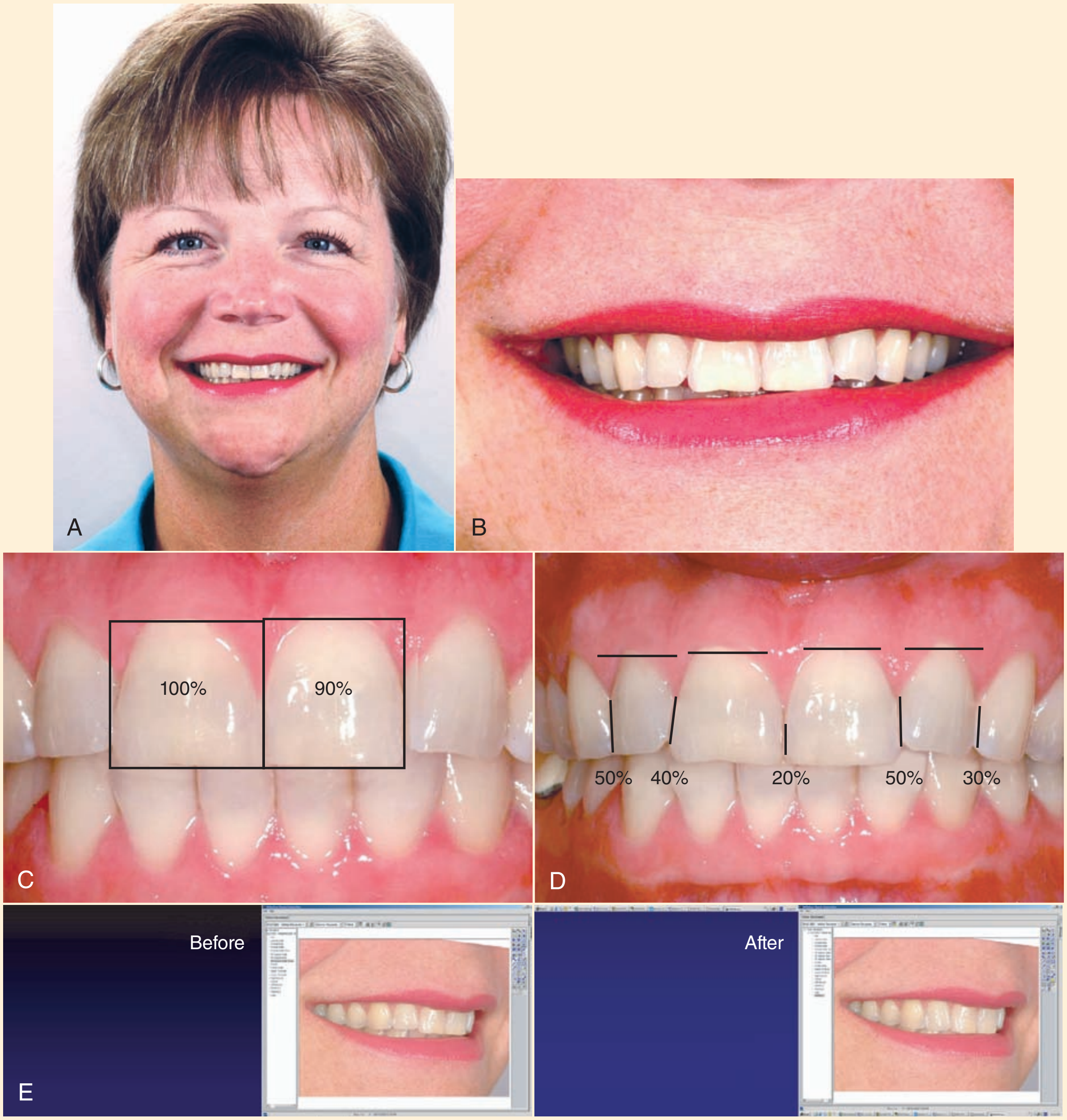

FIGURE 2-39 **A,** This 40-year-old woman wished to have her smile improved and sought orthodontic consultation. **B,** The close-up image of her smile reflects incomplete incisor display on smile and a flat smile arc. **C,** The anterior teeth were disproportionate and contributed to her complaint of "square teeth." Measuring the height-to-width ratio, the left central incisor had a ratio of 9 : 10, whereas the right central incisor was indeed square, with a height-to-width ratio of 1 : 1. **D,** The connectors on this patient were far from ideal (see Figure 2-38, **A** for the connector heights), and the gingival heights are disparate. **E,** To visualize the increased incisor display and effect on the smile arc, an image modification of the oblique close-up smile picture was done to simulate incisor extrusion. With current technology, the images also can be calibrated so that one knows the distance required for this movement and so that a clinician can decide whether this is an attainable goal.

CASE STUDY 2-1 **SMILE REFINEMENT—cont'd**

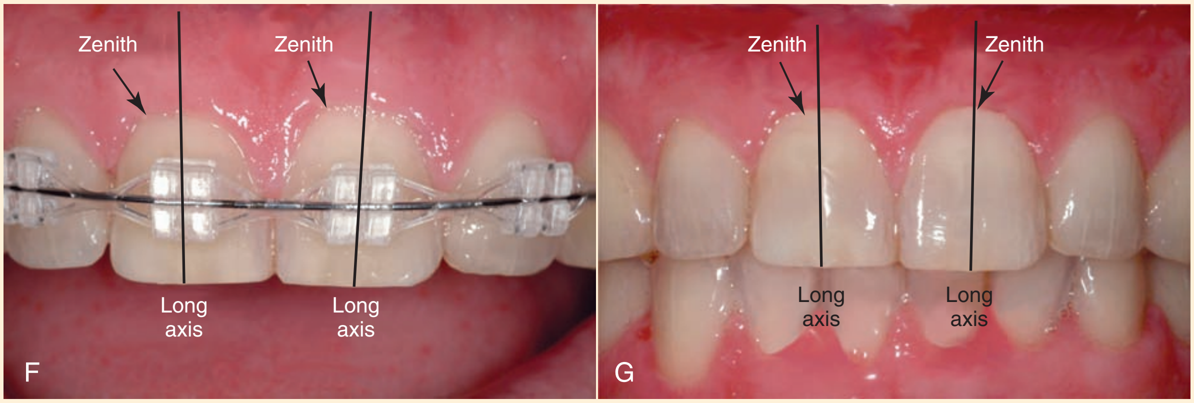

FIGURE 2-39, cont'd **F,** On the right central incisor the zenith was located too far distal to the long axis, and the crown height was shorter than the left central. The left central incisor zenith was located mesially to the long axis of the tooth. **G,** After contouring of the gingival margins with a soft tissue laser, the left central incisor was lengthened, and the zeniths relocated on both teeth.

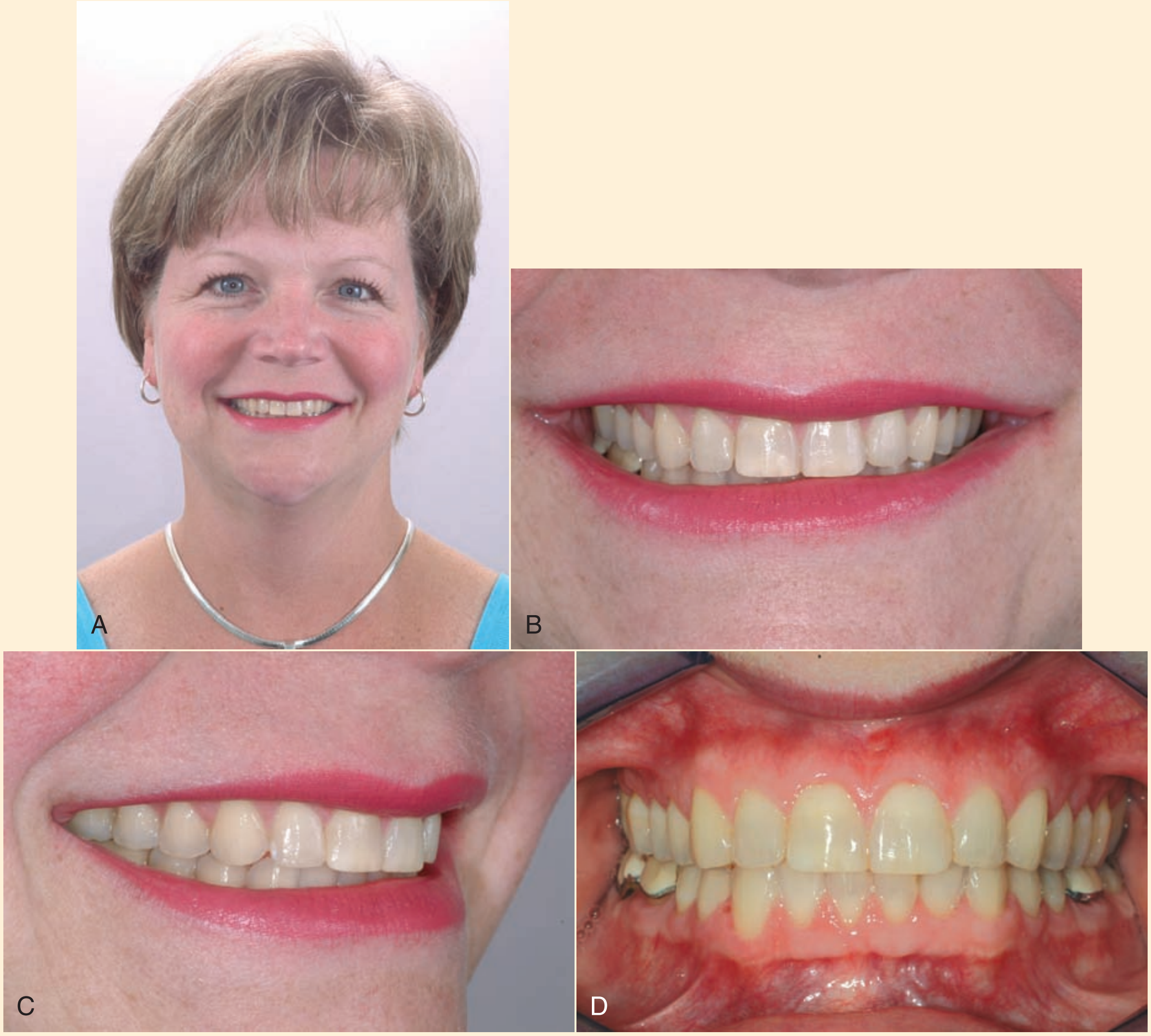

FIGURE 2-40 **A,** The final smile was characterized by increased incisor display on smile. **B,** The close-up smile shows the increased incisor display, greater consonance with the smile arc, and the improved tooth proportionality. **C,** The oblique view demonstrates the adaptation of the maxillary incisors with posterior segments with the smile arc. **D,** The intraoral photographs show, after tooth reshaping and gingival contouring, greatly improved tooth proportionality in terms of height-to-width ratios, embrasures, and gingival contour.

CONCLUSION

The special considerations in orthodontic diagnosis and treatment planning represent the new vistas in orthodontics that reflect the incorporation of artistic elements into our decision-making process. Many of our decisions are now based on proportions, not linear measurements. Shape and form are now important features of contemporary treatment planning, and draw on the talents of the orthodontist to "see" and establish the goals of treatment in terms of health, wellness, and appearance.

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CHAPTER 3

Psychological Aspects of Orthodontics

Leslie Will

OUTLINE

Patient Perceptions
Patients with Psychological Disorders
  Attention-Deficit/Hyperactivity Disorder
  Obsessive-Compulsive Disorder
  Body Dysmorphic Disorder
  Bipolar Disorder
  Panic Disorder
  Depression
  Eating Disorders
  Personality Disorders
  "Difficult" Patients
Patients with Craniofacial Deformities
Summary

Orthodontists learn very early in their careers that moving teeth is only one aspect of taking care of their patients. Every patient is different and every person comes with his or her unique pattern of responding to others, making decisions, and carrying out plans. Each patient's personal experience, family history, and cultural differences will naturally influence individual responses to orthodontic treatment strategies.

Communication between the orthodontist and the patient is extremely important in achieving treatment goals. In addition to encouraging cooperation and maximizing good treatment results and patient satisfaction, good communication is essential from a medicolegal standpoint. Instead of just giving the patient information, the orthodontist needs to be concerned with what the patient understands and expects from treatment.

Research has shown that patients do not always understand or remember what they have been told about their malocclusion or the orthodontic treatment. Mortensen, Kiyak, and Omnell[1] interviewed 29 pediatric patients aged 6 to 12 years and their parents 30 minutes after an informed consent discussion. Both the children and their parents were asked about the reasons for treatment, risks, and responsibilities that were mentioned during the informed consent discussion. It was discovered that although an average of 4.7 risks were mentioned by the orthodontist during each discussion, on average the parents remembered 1.5 risks and the children remembered less than 1. Similarly, 2.3 reasons for treatment were mentioned by the orthodontist during the discussion, but the parents on average remembered 1.7 and the children remembered 1.1. Clearly, not all the desired information is being remembered by the patient or their parents.

PATIENT PERCEPTIONS

Psychological factors may influence a patient's perception of their malocclusion as well as the treatment plan. It is difficult to know or predict how a patient will view his or her individual situation. Fortunately, there are several research approaches that can give some insight as to how patients see malocclusion, and some generalities have been learned that may help orthodontists assess how their patients are likely to react.

One key method is to show the patient profiles. By altering one aspect of the profile in successive photographs or silhouettes and asking the patient to indicate which profile is most like theirs, it is possible to determine how accurately patients can perceive profiles.[2]

A version of this is the Perceptometrics technique that was developed by Giddon et al.,[3] in which computer alterations are made to photographic images, with the feature of interest "morphed" by the computer so that the feature is moved back and forth in one dimension at gradual, predetermined intervals. By clicking on the image, the range of photographs can be traversed, with each photograph being displayed the same amount of time. Patients can then indicate the beginning and end of the acceptable range of profiles by holding down the

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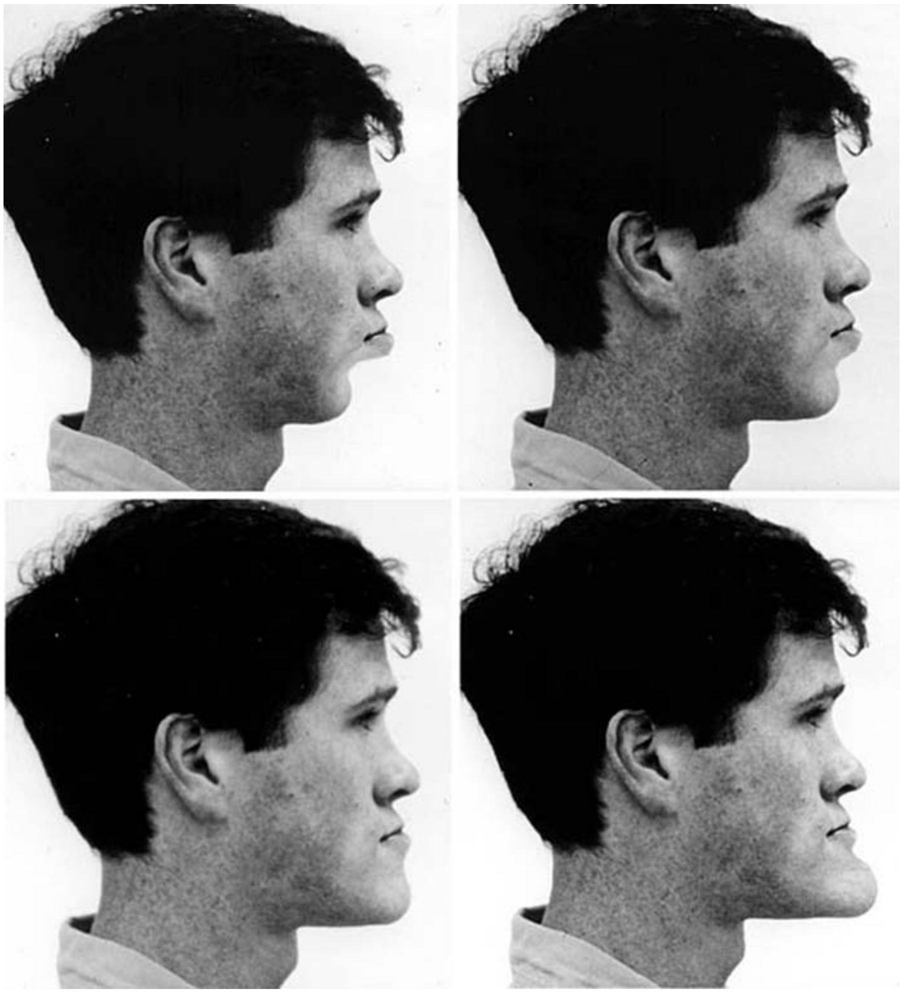

FIGURE 3-1 *(From* American Journal of Orthodontics and Dentofacial Orthopedics, *volume 114, number 6, page 632, Figure 1.)*

computer mouse, and they can also indicate which profile is most attractive. This tool enables clinicians to determine the range of what patients consider acceptable (Figure 3-1).

Many studies have been done using a variety of methods exploring patient perceptions on many aspects of facial aesthetics. Kitay et al.[4] found that orthodontic patients are less tolerant of variations in their profiles than are nonorthodontic patients. To determine their range of acceptability, 16 patients and 14 nonorthodontic adult patients were asked to respond to computer-animated distortions of profiles that distorted the lower third of their own faces using the Perceptometrics program. Both groups of subjects were equally accurate in identifying their own profiles. However, the orthodontic patients had a smaller zone of acceptability (ZA) in features in a control face, with a significant disparity between one feature in their own profile and the most pleasing position for that feature. This suggests that the orthodontic patients are motivated to seek treatment by specific features in their own face that they perceived as undesirable.

Using the Perceptometrics technique, Arpino et al.[5] compared the ZA of profiles selected by orthognathic surgery patients, their "significant others," orthodontists, and oral surgeons. Patients with both Class II and Class III jaw discrepancies evaluated their own photographs with four features altered horizontally (upper lip, lower lip, both lips together, and chin) and one feature, lower facial height, altered vertically. Although there was some variation, the magnitude of the ZA was smallest for the patient, followed by the surgeon, the significant other, and finally the orthodontist. Whereas the patient and the significant other groups differed in only two instances, the orthodontists and oral surgeons had significantly different ZAs for all but the Class II bimaxillary relationship. These results show that orthodontists are most tolerant of different profiles, while the patients themselves are least tolerant, perhaps reflecting the reality that orthodontic treatment compared with orthognathic surgery is a slower biologic process with a wider range of acceptable outcomes.

Hier et al.[6] used the same technique to compare the preferences for lip position between orthodontic patients and untreated subjects of the same age. They found for both males and females that the untreated subjects preferred fuller lips than did orthodontically treated subjects, which is greater than Ricketts' ideal measurement of lip protrusion to the E-line.

Miner et al.[7] compared the self-perception of pediatric patients with the perceptions of their mothers and their treating orthodontists. Using the Perceptometrics technique, the upper lip, lower lip, and chin were distorted as the images moved from retrusive to protrusive extremes in counterbalanced order. The patients, mothers, and clinicians were asked to indicate the ZA for each feature and the most accurate representation of the child's profile, as well as indicate the ZA for a neutral female face. Both patients and mothers were found to overestimate the protrusiveness of the child's actual mandible, and both groups preferred a more protrusive profile for both the child and the neutral face. In addition, the mothers had the smallest tolerance for change in the soft tissue profile. These studies are valuable for pointing out the inherent inaccuracies of patient's perceptions as well as the differing preferences of patients.

These techniques are also useful for exploring perceptions of different racial and ethnic groups. In a study by Mejia-Maidl et al.,[8] 30 Mexican Americans and 30 whites of varying age, sex, education, and acculturation indicate their perceptions of four profiles of individuals of Mexican descent. Using the Perceptometrics program, the authors found that in general, Mexican-Americans preferred less protrusive lips than did the whites. In addition, there was a wider ZA or tolerance for male lip positions and female lower lip position among the whites than among the Mexican Americans of low acculturation. These observations were not true of highly acculturated Mexican Americans, who may have assimilated American cultural aesthetic preferences. Park et al.[9] compared the perceptions of Korean American orthodontic patients with those of white orthodontists and Asian American orthodontists. Statistically significant differences were found between the Korean American patients and the white orthodontists for the acceptable and preferred positions of the female nose and the male chin, finding that the Korean Americans preferred a more protrusive nose for females and a more retrusive chin for males. McKoy-White et al.[10] compared the ZA for black females among black female patients, black orthodontists, and white orthodontists. The patients were also asked to correctly identify their most accurate pretreatment and posttreatment profile. It was found that the white orthodontists preferred flatter profiles than did the black women, who in turn preferred fuller profiles than the black orthodontists. Although the patients could correctly identify their own post-treatment profile, they all recalled a fuller pretreatment profile than they actually had.

These studies underscore the importance of racial and cultural influences on the esthetic perceptions and preferences of orthodontic patients. Such studies are also valuable for pointing out the inherent inaccuracies of patients' perceptions as well as the cephalometric bases of their facial preferences. Orthodontists need to be sensitive to differences between patients' and their own preferences in formulating treatment plans.

PATIENTS WITH PSYCHOLOGICAL DISORDERS

Different and unanticipated behaviors among patients often become challenging for the orthodontist. When does such behavior become a problem? When are some behaviors simply difficult, while others may be evidence of pathology? How do we recognize these difficulties and deal with them?

The preceding research explores the perception of psychologically healthy individuals. However, many orthodontic patients may have preexisting psychological disorders when they present for orthodontic treatment. Many patients who seek orthodontic treatment are functioning within society while being treated for a psychological disorder. Although these patients are usually controlled, it is important to recognize how these disorders may be manifested. In addition, orthodontists should be aware of side effects of medications that may have implications for oral health.

Common psychological conditions are delineated by the American Psychiatric Association in the *Diagnostic and Statistical Manual of Mental Disorders*, or *DSM-IV-R*.[11] The most common conditions that orthodontists may encounter are attention-deficit/hyperactivity disorder (ADHD), obsessive-compulsive disorder (OCD), body dysmorphic disorder, bipolar disorder, panic disorder, and depression. In addition, there are some personality disorders and other psychological conditions, such as eating disorders, that may acutely affect adolescents.

Attention-Deficit/Hyperactivity Disorder

ADHD is a chronic disorder characterized by inattention, impulsivity, and hyperactivity. Worldwide, ADHD affects more than 5% of those under 18 years of age[12] and more than 4% of the adult population.[13] Some diagnostic criteria, however, are nonspecific and the disorder is overdiagnosed, with some signs of ADHD being observed in almost everyone some time in their life. Nevertheless, the main criterion is that the behavior must cause impairment in the individual's life for a prolonged period of time.[11]

The precise etiology of ADHD is not known. Although it is considered to have a genetic basis in the majority of cases, it is most likely that a combination of genes, rather than a single gene, is responsible.[14] Approximately 20%

of cases may be due to prenatal brain injury, such as hypoxia accompanying prematurity or tobacco smoke, or trauma. Food allergies and food additives are suspected as a possible aggravating factor.

Medication is considered to be the most effective method of treating ADHD.[15] However, behavioral therapy for parents of children with ADHD may also be useful to assist parents in managing their children most effectively.

Hyperactivity and the inability to focus can be problems during orthodontic treatment. Patients with ADHD may have trouble sitting still during procedures and may not be compliant in maintaining good hygiene, wearing elastics, or performing other tasks because of forgetfulness and inattentiveness. These patients can be best managed by giving short, clear instructions and giving written instructions or reminders to them or their parents, with follow-up questions to determine their comprehension and rewards for successful compliance. Dental prophylaxis may be needed more frequently to avoid decalcification and caries. To increase the likelihood of treatment success, it may be wise to avoid treatment plans that require a high degree of patient compliance. During treatment, it is often helpful to give the patient breaks during prolonged procedures.

Obsessive-Compulsive Disorder

Obsessive-compulsive disorder (OCD) is characterized by intrusive thoughts and repetitive, compulsive behaviors.[11] The patient's behavior is intended to reduce the anxiety that accompanies the intrusive thoughts. This disorder affects 1% to 4% of the population and is often associated with eating disorders, autism, or anxiety disorders.[16]

Although OCD is also considered to be genetic in etiology,[17] specific genes causing OCD have not been identified, and the molecular basis of the disorder has not been determined. The clinical variability suggests that the etiology is heterogeneous, with the possibility of gene–gene and gene–environment interactions.[18]

Treatment of OCD can take one of two forms. For milder cases, cognitive-behavioral therapy (CBT) is usually used. During this form of treatment, the patient is exposed to a feared stimulus with increasing intensity and frequency so that the patient will learn to tolerate what had previously caused anxiety. In addition to CBT, more severe cases and adult patients usually require medication, such as selective serotonin reuptake inhibitors (SSRIs), including clomipramine (Anafranil), fluoxetine (Prozac), fluvoxamine (Luvox), paroxetine (Paxil), and sertraline (Zoloft).[17] One side effect of this class of psychopharmacologic agents is xerostomia, so orthodontists should be aware of this possibility and advise patients accordingly.

Body Dysmorphic Disorder

Body dysmorphic disorder (BDD) is characterized by an intensely negative emotional response to a minimal or nonexistent defect in the patient's appearance. The head and face are common foci for this preoccupation, so orthodontists may see patients who have excessive concerns about their dentofacial appearance. Other characteristics of this disorder involve multiple consultations about their perceived defect, an obsessive concern with appearance, and emotional volatility. This preoccupation may lead to stress and related disorders and behaviors. Patients are likely to become socially isolated since so much time and attention are devoted to this concern.[19]

Diagnosis can be difficult and misleading, without recognition that BDD involves more than obsessive thoughts. Underdiagnosis is also common, because many patients may not seek help. Approximately 1% of the population may suffer from BDD, which may coexist with other disorders, such as depression and OCD.[20,21]

BDD is also treated most successfully with SSRIs, although CBT can help.[22] Using photographic imaging of the patient's own face as a reality check may help with some patients (D. B. Giddon, personal communication). The cognitive aspect of therapy aims to restructure faulty beliefs that lead patients to focus on an imagined defect. The behavioral therapy works to reduce the social avoidance and repetitive behaviors. It is not known which mode of therapy is better or if a combination is best.[22]

If this disorder is not treated, most patients will seek dental, medical, or surgical treatment to "correct" their flaws, which usually fails.[19] Physical improvement, however, does not signify psychological improvement. Dissatisfied patients may become violent toward themselves or attempt suicide. Thus, orthodontists and other clinicians who are consulted are advised to be particularly wary of such patients, who can disrupt office routines, leading to great frustration for both clinicians and patients.

Even if patients do not have a diagnosis of BBD, they may have excessive concerns about minimal or nonexistent deformities or malocclusion. With such patients, limits on therapeutic intervention must be set. Patients should be given realistic options with definite endpoints, including the option of no treatment. Concrete comparisons and predictions should be shown to reinforce reality and not lead to unrealistic expectations. Treatment options and the final treatment plan, along with possible obstacles to ideal results, should be put in writing. Treatment should be stopped or the patient referred to other health professionals.

Bipolar Disorder

Bipolar disorder, formerly known as manic-depressive disorder, consists of two phases: depression and mania.

These mood swings are so severe as to interfere with normal life. The lifetime prevalence of this disorder is 1.6%, although the course of the disorder varies. The peak time of onset is between 15 and 24 years, stabilizing in later years.[23]

Accompanying the mood swings can be a variety of other disorders. It is estimated that 50% of patients also abuse illegal substances. Between 25% and 50% attempt suicide, with 10% to 15% being successful.[23]

The pathogenesis of this illness consists of neurochemical abnormalities with an etiology that is at least partially genetic. If one parent is affected, there is a 25% risk that children will be affected, but if both parents are affected, the risk jumps to 50% to 75%. There is a 70% concordance in identical twins.[23]

Treatment for BD with mood stabilizers such as lithium, valproate, or carbamazepine is most important.[23] Drugs that calm agitation, such as chlorpromazine or olanzapine, may also be useful. Antidepressants are not usually prescribed because they may trigger mania.

Of concern in bipolar disorder is that for most patients, 5 to 10 years elapse between the beginning of symptoms and treatment.[23] This is probably due to the fact that for a certain period of time, the mood swings do not seem serious enough to warrant treatment, and people will often try to accommodate to their symptoms as long as possible before submitting to psychiatric care. During this time, however, these patients may be difficult to manage, with periods of depression and mania. For the orthodontist, bipolar disorder may be manifested with poor hygiene, a lack of compliance, and a general apathy toward treatment. In the patient under treatment, medications can produce xerostomia, with its deleterious effects on the dentition.[23]

Panic Disorder

Panic disorder (PD) is diagnosed when the patient experiences sudden, recurrent panic attacks consisting of heart palpitations, dizziness, difficulty breathing, chest pains, and sweating that are unrelated to any external event and are not due to any medical condition. It is estimated that 2% of males and 5% of females are affected in their young adult years, and the majority have concurrent depression. This condition can be extremely disabling because the patient often avoids certain situations in an effort to prevent recurrences, with the result that patients are socially and vocationally impaired.

A genetic susceptibility to PD combined with environmental stresses is likely, and the heritability is estimated to be 48%.[24] It has been hypothesized that there is a mutation in 13q, with an organic defect in the amygdale and hippocampus, that portion of the mid-brain responsible for emotion and memory with input from the visual, auditory, and somatosensory systems.[25] In PD, the amygdala misinterprets sensations from the body, leading to the characteristic extreme reactions.

Treatment for PD consists of medication either by itself or in combination with CBT. Meta-analysis has shown that a combination is most effective,[26] although SSRIs have many possible side effects that may affect the oral health of patients, including xerostomia, glossitis, gingivitis, stomatitis, and loss of the sense of taste. Suicide has also been reported. In addition, interactions are also possible between SSRIs and erythromycin or codeine.

Depression

Depression is one of the most common psychiatric disorders, affecting an estimated 20% of the population at some time in their lives.[27] The course of depression may vary widely; it may affect a patient once or recur; it can appear gradually or suddenly and can last a few months or a lifetime. Not only are patients with depression at higher risk for suicide, they also have a higher mortality rate from other causes such as accident, trauma, or homicide. Depression is the leading cause of disability in North America.

Depression can take many forms, but common symptoms, lasting for at least 2 weeks, are a pervasive low mood, a loss of interest in usual activities, significant (5%) weight gain or loss, change in sleep patterns, loss of energy, persistent fatigue, recurrent thoughts of death, and a diminished ability to enjoy life.[28] Adolescents are more apt to be irritable and act out when they are depressed, but patients generally report feeling empty and anxious, with fatigue and decreased energy. It is sometimes difficult to distinguish between “normal” or situational depression, which is a natural response to trauma or illness, and clinical depression, which may be related to underlying endogenous factors. One distinguishing characteristic of normal depression is that these patients still can communicate, make their own decisions, and participate in their own care. Patients with pathologic depression have symptoms that are out of proportion to the circumstances.

The cause of depression is linked to a lack of stimulation of the postsynaptic neurons in the brain. There is an increase in monoamine oxidase (MAO) A, an enzyme that decreases the concentration of serotonin and other monoamines that help maintain a positive mood. As with other psychological disorders, there is a genetic component, although it is poorly defined.[29]

Because orthodontic patients come regularly for appointments and usually interact with the orthodontist and office staff, orthodontists are in a good position to notice whether their adolescent patients exhibit such symptoms or signs of depression. Orthodontists should be particularly attentive to patients who have dropped out of their normal activities, changed their appearance, report insomnia, have abrupt deterioration in academic performance in conjunction with a lack of interest in their usual activities, or show signs of drug or alcohol abuse.

Treatment for depression, as with other disorders, consists of a variety of drugs and psychotherapy.[29] In addition to pharmacologic and psychological intervention, alternative therapies such as electroconvulsive therapy, hypnotherapy, meditation, and diet therapy have been suggested. Hospitalization may become necessary if suicide is a possibility. Drugs currently used for depression include SSRIs such as sertraline (Zoloft), fluoxetine (Prozac), citalopram (Celexa), and paroxetine (Paxil); MAO inhibitors; and dopamine reuptake inhibitors such as bupropion (Wellbutrin and Zyban). SSRIs have not been found to work significantly better than placebo for moderate depression but have been found to be effective for severe depression. MAO inhibitors are effective but can have interactions with decongestants or tyramine-rich foods such as cheese. Dopamine reuptake inhibitors are better than SSRIs for fatigue and insomnia.

Nondrug therapies for depression, such as CBT, are directed at helping the patient learn to cope with their symptoms and improve interpersonal communication. In supportive therapy, patients may also discuss their problems with others who can share strategies for coping with their illness. In family therapy, the entire family learns how to undo patterns of destructive behavior.[29]

Eating Disorders

Eating disorders, including anorexia nervosa or bulimia nervosa, affect up to 2% of adolescent and young adult females, although they can affect both sexes at many ages.[28] The fundamental defect lies in the distorted body image that leads patients to control their weight by extreme dieting or vomiting. Patients usually go to great lengths to hide their symptoms and behaviors, so that close family members often are unaware of their existence. Bulimia and anorexia can lead to severe metabolic disturbances and even death, and thus they require treatment.

Both anorexia and bulimia have oral manifestations. Bulimia may lead to dental erosions, which can be sometimes be noted as extruding amalgams, as well as dentinal hypersensitivity and salivary gland hypertrophy. Both conditions can be accompanied by cheilosis.

If orthodontic patients are suspected of having an eating disorder, these concerns should be addressed directly. Therapy for eating disorders consists of CBT, so that patients can develop realistic ideas about how much they should eat, what is good nutrition, and their own body image. SSRIs can also be used.

Personality Disorders

While depression, BDD, and OCD are classified by the *DSM-IV* as Axis I disorders and are predominantly related to mood, personality disorders are classified as Axis II disorders (i.e., disorders that involve maladaptive behaviors and patterns of thinking that lead to problems at home, school, and work). Personality disorders most frequently seen are the narcissistic personality, borderline personality disorder (BPD), and the antisocial personality disorder (APD). It is estimated that the prevalence of these personality disorders ranges from 4.4% to 13% in the United States.[30] Environmental influences such as prior abuse, poor family support, family disruption, and peer influences, as well as biological causes, are important risk factors for the development of such disorders.

Patients with narcissistic personalities believe that they are special and therefore entitled to special treatment. The typical narcissistic patient has a very brittle self-esteem and a strong need for approval, which are manifested as arrogance and demands for special attention. These patients are thus more intolerant of minor complications and are more likely to seek legal recourse when dissatisfied.

BPD has an estimated prevalence of 0.7% to 2.0%.[30] It is characterized by erratic moods, impulsivity, and poorly controlled anger. These behaviors can lead to unstable relationships and chronic interpersonal problems. One interesting feature is that patients with BPD often begin treatment with an extremely positive view of the orthodontist but, with treatment, quickly changes to hatred and anger in response to complications.

APD affects more males than females by a ratio of 4 or 5 : 1, with an overall prevalence of 2% to 3%.[30] Those affected by APD exhibit unacceptable behavior such as lying, theft, destructive behavior, and aggression to people and animals, accompanied by a lack of remorse.

Patients with any form of personality disorder can be difficult to manage in an orthodontic office, being disruptive and trying for clinicians. Such individuals may be hard to identify or label, even though they may not be compliant and may show some signs of depression or substance abuse and even attempted suicide. Staff members need to handle these patients with evenhandedness, not allowing them to disrupt the office procedures or abuse office personnel. Orthodontists should beware of excessively dependent or manipulative behaviors, which can cause conflict among staff members. If necessary, care can be discontinued and the patient dismissed.

“Difficult” Patients

As noted earlier, patients with no known psychopathology can still be difficult to manage, exhibiting a number of different behaviors that are disruptive, hostile, or otherwise difficult for the orthodontist to handle. According to Groves,[31] they can be categorized into four distinctive types:

Dependent clingers have needs for reassurance from their caregiver that escalate. Patients are initially reasonable in their needs but become progressively more helpless, ultimately becoming totally dependent upon their doctors. These patients must be given appropriate limits with realistic expectations. Clear verbal and written instructions can be helpful in reinforcing the limits of patient access to the professional staff.

Entitled demanders are also needy but manifest it as intimidation and attempts to induce guilt. They have a need to control the situation and often make threats, either overt or implied, in order to get what they want. Their aggressive behavior may be due to feelings of dependency and fear of abandonment. These patients are best dealt with by validating anger but redirecting the feelings of entitlement to realistic expectations of good care. Again, limits must be placed so that office procedures are not disrupted.

Manipulative help-rejecters focus on their symptoms but are resigned toward failure. They seem satisfied with a lack of improvement. Clearly, these patients who are difficult to treat must be involved in all decisions and should have regular appointments. Because they must either agree to all treatment or choose not to proceed, the orthodontist does not have the responsibility for the success of the treatment.

Self-destructive deniers take pleasure in defeating any attempts to help them. They do not seem to want to improve. These patients may be sufficiently depressed to consider not rendering or limiting treatment.

In general, all demanding and needy patients should have limits placed on their behavior at the time when treatment alternatives are discussed. Orthodontists should not promise too much in describing treatment plans and outcomes. They should describe how they would address the orthodontic needs, noting potential problems and obstacles to the treatment, and explain how progress might be evaluated. In fact, some variation of the Perceptometrics method might be helpful to present patients with an acceptable range of suggested treatment outcomes (D. B. Giddon, personal communication). This will minimize the possibility that patient expectations are too high. As Groves commented, “Difficult patients are typically those patients who raise ‘difficult’ feelings within the clinician.”[31] Orthodontists must learn to address these difficult feelings and deal with them. The orthodontist should remain friendly, unemotional, and professional at all times. Emotional outbursts should be responded to with an acknowledgment of feelings but an expectation of appropriate behavior. Noncompliance must be countered with an appropriate alternative treatment plan. The clinician and staff must avoid being provoked and remain professional and emotionally neutral while maintaining a correct office atmosphere.

PATIENTS WITH CRANIOFACIAL DEFORMITIES

Orthodontists may see some patients with facial deformities or other disfigurement. Their orthodontic treatment may be a part of a coordinated surgical-orthodontic plan to address the deformity or may be isolated. Whatever the circumstances, these patients will be fundamentally different psychologically from patients who are not deformed. Pertschuk and Whitaker[32] compared a group of 43 patients with craniofacial anomalies between the ages of 6 and 13 with children matched for age, sex, intelligence, and family income to determine differences in psychological functioning before surgery, and they studied levels of anxiety, self-concept, social experiences, intelligence, and personality characteristics. They found that the craniofacial patients were more anxious and more introverted and had a poorer self-concept. Their parents reported teasing from peers about their facial appearance. Treatment was being sought out of a desire to improve appearance, but patients could not specify what they wanted to change. When these patients were evaluated 12 to 18 months after surgery, they demonstrated reduced levels of anxiety but more negative social interactions. Pertschuk and Whitaker thus concluded that modest improvements in psychological adjustment were due to craniofacial surgery.

Pillemer and Cook[33] evaluated 25 patients aged 6 to 16 years at least 1 year after craniofacial surgery and found that these children still exhibited an inhibited personality style, low self-esteem, impaired peer relationships, and greater dependence on significant adults. They concluded that treatment per se does not solve psychological issues, suggesting that long-term follow-up and support from interdisciplinary teams may be of greater benefit.

Sarwer et al.[34] examined 24 adults born with a craniofacial anomaly in terms of their body image dissatisfaction, self-esteem, quality of life, and experiences of discrimination and compared them with an age- and gender-matched control group who were not disfigured. The adults with craniofacial disfigurement reported significantly greater dissatisfaction with their facial appearance, a significantly lower self-esteem, and a significantly lower quality of life than the control group. In addition, 38% of patients reported that they felt they had been discriminated against on the basis of their facial deformity. It is interesting to note that the psychological functioning was not related to the number of surgeries, but the degree of residual facial deformity was correlated with the dissatisfaction with facial appearance. It should also be noted that these problems are by no means universal among adults with facial deformities.

These studies point out the psychological differences in patients whose self-image is intrinsically different. Clinicians should realize that these patients have a much different perspective on orthodontic treatment. Their expectations of treatment outcome may therefore also be quite different, and this should be explored when orthodontic treatment is discussed.

The most common facial deformity that orthodontists will see is cleft lip and palate. Considerable research has been done examining the psychological aspect of this congenital anomaly. Kapp-Simon[15] discussed *self-concept,* defining it as "a complex summary of the multiple perceptions individuals have about themselves. It includes general and specific judgments about one's self worth, a personal evaluation of one's capabilities, and an internalization of others' reactions to one's self and behavior. … It provides a framework for personal goal setting, has a significant impact on social behavior, and is a crucial element in personal happiness and satisfaction." She explored whether primary school-age children with clefts have negative self-concepts by testing 50 children with a variety of clefts using the Primary Self Concept Inventory (PCSI) and compared the results from tests administered to 172 children without clefts. The PCSI includes a variety of factors that contribute to self-concept, such as physical size, emotional state, peer acceptance, helpfulness, success, and student behavior. Children scoring in the bottom 50th percentile for a given category were considered to have an undesirably low self-concept in that area. Kapp-Simon[15] found that the children with clefts had low self-concepts based on the following areas: social self, emotional state, and helpfulness. Thus, it is apparent that this group of children felt stigmatized by their cleft from a very early age and therefore can be expected to have much different attitudes toward orthodontic treatment from those without clefts.

An important subset of patients with facial deformities includes those who were born without dentofacial deformity but acquired it after birth from either trauma, tumor, or disease. Because these patients had normal faces or occlusions prior to the insult, they may have more psychological stress in adapting to their acquired dysmorphic appearance than those patients who have never known any other morphology. Patients who have congenital anomalies have had time to incorporate the defect into their body image,[35] but patients who suddenly lose their normal appearance have a much more difficult time coping with their deformity. Consequently, their expectations from treatment may be quite different from those patients who have never had a "normal" face. Because the responses to acquired or congenital deformities may differ, it is critical that the patient's expectations and wishes be discussed in detail and that the orthodontist discusses realistically what can be achieved.

SUMMARY

Every patient has individual perceptions, desires, needs, and related behavior, some of which are outside the usual experience of most orthodontists. It is hoped that the information provided in this chapter will help orthodontists to more effectively manage patients with abnormal or difficult perceptions and behaviors. Clear communication is critical when discussing orthodontic problems, proposed treatment, and treatment alternatives. In addition, the clinician must become completely familiar with the patient's medical and psychosocial history, needs, questions, and perceptions. The patient must also be given clear guidelines for office procedures. In this way, many problems arising from abnormal psychological problems and behaviors can be minimized.

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CHAPTER 4

Craniofacial Imaging in Orthodontics

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OUTLINE

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- **Historical Perspectives on Imaging in Orthodontics**
- **Imaging Goals and Strategies**
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  - Clinically Determined Imaging Goals
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    - *Panoramic Projections*
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    - *Corrected Tomography of the Temporomandibular Joint*
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HISTORICAL OVERVIEW

Images of the craniofacial region are an important component of the orthodontic patient record. The gold standard that orthodontic records attempt to achieve is the accurate replication or portrayal of the "anatomic truth." The anatomic truth is the accurate three-dimensional anatomy, static and in function, as it exists in vivo. Many technologies, including imaging, articulators, jaw tracking, and functional analyses, are included in the orthodontic record to depict the anatomic truth. Imaging is one of the most common tools that orthodontists use to measure and record the size and form of craniofacial structures. Imaging traditionally has been used in orthodontics to record the current state of limited or grouped anatomic structures. Despite the diverse image acquisition technologies currently available, the types and standards for imaging presently used in practice have been adopted in an effort to balance the anticipated benefits with associated costs and risks to the patient. Because of these considerations, orthodontists routinely use an array of two-dimensional static imaging techniques to record the three-dimensional anatomy of the craniofacial region. For example, the anatomy is captured by site-specific images including panoramic and periapical radiographs and photographs for teeth; tomographs and magnetic resonance imaging (MRI) for temporomandibular joints (TMJs); and cephalometric radiographs for the facial skeleton. Although site-specific imaging enhances detail, it also segments anatomy by creating a patchwork of separate images to represent an entire structure. The process of segmenting anatomy

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results in related anatomic structures being differentiated arbitrarily based on the point of view selected and the associated imaging geometry of that view. This anatomic parsing places a difficult, if not impossible, responsibility on the clinician to reconstruct the true anatomy mentally. The limitations of this approach have resulted in the development of standardized analysis methodologies that can be used to describe the anatomic information contained in the images. This analysis uses linear and angular measurements that are generated manually and with computer assistance. These measurements often have been incorporated into research databases for use in predicting growth and for evaluating treatment outcomes. Although the use of imaging in orthodontics has been adequate, the fulfillment of the ideal imaging goal of replicating the anatomic truth has been limited by the available technology, the quality of the databases used to generate data, and by tradition or legacy systems. A legacy system (status quo system) with repetitious use becomes the surrogate truth and therefore is difficult to replace even when a more accurate method exists. These limitations in current orthodontic imaging strategies have resulted in the use of a conglomeration of geometrically unrelated, inaccurate two-dimensional images for diagnosis and treatment planning. Ideally, multiple image sets of a patient would be entered into a common three-dimensional database to produce an accurate interactive multidimensional patient-specific model, representing the desired craniofacial structures and tissues. This "smart" model should have the ability to divulge relevant information as requested by the clinician and would contain multidimensional information that includes three-dimensional space, time and anatomic attributes such as tissue resiliency, tissue type, and structural objects. The smart model would provide time-dependent three-dimensional location and interrelationships of its structural objects, including the jaws, landmarks, TMJ disks, teeth, and lips. The addition of functional attributes to this model such as jaw tracking, electromyographic recordings, and bite force measurements would allow computation of resultant stress-strain maps within the jaws and related structures. Stress-strain maps would assist in understanding the biomechanical relationships among form, function, treatment outcomes, and treatment stability. This approach to craniofacial imaging would provide an accurate representation of the anatomic, physiologic, and biomechanical truth leading toward greater accuracy in the diagnosis, treatment planning, treatment monitoring, and eventual treatment of orthodontic patients.

HISTORICAL PERSPECTIVES ON IMAGING IN ORTHODONTICS

Cephalometry, or the measurement of the head, was developed as an anthropologic technique to quantify shape and sizes of skulls. The discovery of x-rays by Roentgen in 1895 revolutionized medicine and dentistry. About 36 years later, traditional cephalometry in two dimensions, known as roentgenographic cephalometry, was introduced to the dental profession by Broadbent[1] and has since remained relatively unchanged. Since these early years, cephalograms have been used widely as a clinical and research tool for the study of craniofacial growth, development, and treatment. However, because of the erroneous assumptions that are inherent to traditional two-dimensional cephalometry, use of this method for deriving clinical information as a basis for determining treatment plans has been questioned.[1,5,31,37,49] The following issues question the validity of two-dimensional cephalometry to derive clinical information used in treatment planning:

1. A conventional head film is a two-dimensional representation of a three-dimensional object. When a three-dimensional object is represented in two dimensions, the imaged structures are displaced vertically and horizontally. The amount of structural displacement is proportional to the distance of the structures from the film or recording plane.[6]
2. Cephalometric analyses are based on the assumption of perfect superimposition of the right and left sides about the midsagittal plane[6] (Figure 4-1). A perfect cube aligned in a "cephalostat" will NOT show superimposition of the right and left sides due to the "differential magnification" between right and left sides. If the images of the "right and left" sides were in alignment, the "cube" would have to be asymmetric. Perfect superimposition is observed infrequently because facial symmetry is rare and because of the relative image displacement of the right and left sides as described previously. These inherent technical limitations do not produce an accurate assessment of craniofacial anomalies and facial asymmetries.
3. The projection geometry precludes the ability to acquire accurate dimensional information aligned in the direction of the x-ray beam.
4. A significant amount of external error, known as radiographic projection error, is associated with image acquisition. These errors include size magnification, errors in patient positioning, and projective distortion inherent to the film–patient–focus geometric relationships.
5. Manual data collection and processing in cephalometric analysis have been shown to have low accuracy and precision.[43]
6. Significant error is associated with ambiguity in locating anatomic landmarks because of the lack of well-defined anatomic features, outlines, hard edges, and shadows and variation in patient position.[6] Such landmark identification errors are considered major source of cephalometric errors.[7,8] Despite these limitations of cephalometry, many cephalometric analyses have been developed to help diagnose skeletal

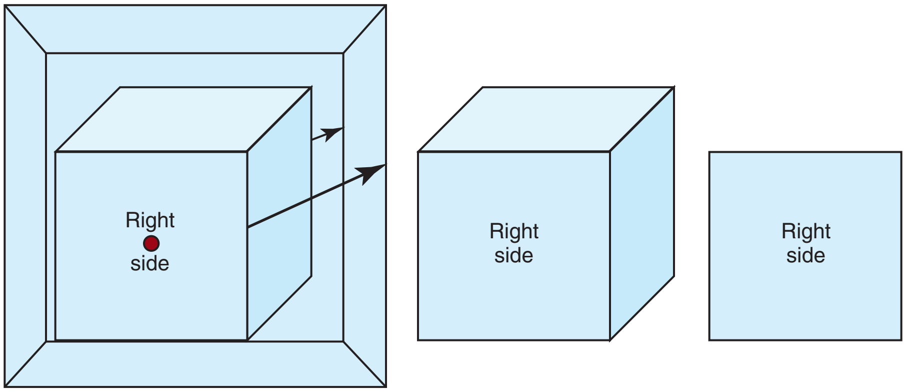

FIGURE 4-1 Geometric distortion of cephalometry. An image of a cube will display asymmetric left and right sides due to distortion. As a corollary, an image of a cube with symmetric left and right sides could only result from an asymmetric cube shape.

malocclusions and dentofacial deformities. However, several investigators have questioned the scientific validity of such analyses.[9] Vig[10] reported the lack of validity of cephalometric analyses as a diagnostic instrument and demonstrated that conclusions drawn from the same cephalograms varied significantly depending on the analysis used. According to the biometrician Fred Bookstein,[4] traditional cephalometrics have neither valid biologic parameters nor valid biometric predictions. The cumulative errors associated with traditional two-dimensional cephalometry have been reported to be significant enough to affect diagnosis and treatment planning.

Hatcher[11] reviewed and categorized sources of error inherent to traditional cephalometrics. These errors include those caused by internal and external orientation and those related to geometry and association as outlined next:

Internal orientation error: This error refers to the three-dimensional relationship of the patient relative to the central x-ray beam or imaging device and assumes that a minimal error of this type occurs with a specific and consistent head position. Because this is not always true, an internal orientation error is introduced.

External orientation error: This error refers to the three-dimensional spatial relationship or alignment of the imaging device, patient-stabilizing device, and the image-recording device. Minimal error is assumed when the x-ray source is 60 inches from the mid-cephalostat as the central ray passes through the ear rods and the beam is horizontal to the horizon and perpendicular to the film plane. Furthermore, the distance from the mid-cephalostat plane to the film plane should be known and be consistent between images. Any deviations from these assumptions will introduce errors into the final image.

Geometric error: This error primarily refers to the differential magnification created by projection distance between the imaging device, recording device, and a three-dimensional object. For example, structures farthest from the film will be magnified more than objects closer to the film. This error is related to the divergence of the x-ray beam on its path from the x-ray source to the recording device.

Association error: This error refers to the difficulty in identifying a point in two or more projections acquired from different points of view. The difficulty in identifying the identical point on two or more images is proportional to the magnitude of change in the angle of divergence between the projections.

Computers have been used to assist in reducing these errors; however, they also may introduce errors because of pixel size, loss of color and contrast information, and incomplete calibration. Therefore, in an attempt to eliminate these random and systematic errors, methods have been developed to provide three-dimensional representation of the craniofacial complex. The first effort was proposed by Broadbent[1] and Bolton, who originally introduced the roentgenographic cephalogram and stressed its three-dimensional nature from its inception in 1931. These investigators described the Orientator, which attempted to reduce association and geometric errors in lateral and posterior anterior head films. The Orientator did not overcome all of the flaws and limitations inherent to two-dimensional cephalograms. The residual error of the Orientator method included variations in identification of identical landmarks from two different cephalograms and differential enlargements of the two views.[13] Contemporary efforts at minimizing errors and achieving accurate three-dimensional representation of the craniofacial complex have included computed tomography (CT) and computer-aided design software,[14] which are described later.

An alternative approach to three-dimensional location of landmarks uses the principle of coplanar stereometry. This technique was adapted to cephalometric imaging by using the principles of stereophotogrammetry. Stereocephalometric instrumentation was developed that produced coplanar stereo pair images.[13,15] The limitation of this approach has been the expensive construction of the stereophotogrammetric machinery and the error introduced by patient movement during the acquisition of the two coplanar stereo films.

IMAGING GOALS AND STRATEGIES

General Imaging Goals

Common orthodontic imaging goals included anatomic feature detection and morphologic measurements. Anatomic features include orthodontic landmarks and anatomic descriptors that characterize normal and abnormal anatomy. The ideal imaging tool balances information quality, ease of use, risk, and cost. One should take the following imaging goals into consideration during the design of an imaging protocol:

1. Image the entire region of interest.
2. View the region of interest in at least two planes at right angles to each other (multidimensional perspective).
3. Obtain images with maximum detail, minimal distortion, and minimal superimposition.
4. The diagnostic value of the imaging study must be in balance with the cost and risk associated to obtain the study.

Clinically Determined Imaging Goals

In general, the purpose of craniofacial imaging is to help solve specific clinical problems. Craniofacial imaging is used to independently decipher one or more of the following categories of information or to interpret the complex interrelationships between craniofacial diagnosis, growth, and treatment by deriving information in two or more of the following categories.

1. Identify normal and abnormal anatomy.
2. Determine root length and root alignment.
3. Establish boundary conditions (alveolar and cortical bone housing the teeth) and the angulations of the teeth to the boundaries of the bone (i.e., in transverse, the “torque” of the teeth relative to the anatomic configuration of the maxilla and mandible).
4. Determine relationships between tooth space requirements and jaw dimensions.
5. Determine maxillomandibular spatial relationships.
6. Determine status of the TMJs.
7. Determine past, present, and expected craniofacial growth magnitude and direction.
8. Determine effects of treatment on the craniofacial anatomy.
9. Identify and localize supernumeraries and impacted teeth.

CONVENTIONAL CRANIOFACIAL IMAGING METHODS

The following is a brief review of imaging methods most widely used by the orthodontic profession.

Hard Tissue Imaging

Cephalometric Radiography. Despite the limitations discussed previously, cephalometric radiography remains a vital clinical tool used for gross inspection, to describe morphology and growth, to diagnose anomalies, to forecast future relationships, to plan treatment, and to evaluate growth and treatment results.[5] The mainstay of cephalometry is that it is the only practical quantitative method that permits the investigation and evaluation of the spatial relationships between cranial and dental structures(see Chapter 2). Although criticized for its inability to display three-dimensional detail, cephalograms provide relatively high projectional resolution compared with other images, including computed tomograms. Fine detail in bony anatomy is evident, and the trained eye can resolve some structures smaller than 0.1 mm.[16] Lateral cephalograms provide pertinent information on skeletal, dental, and soft tissue morphology and relationships, whereas posteroanterior cephalograms are used primarily to assess skeletal and dental asymmetries. Although posteroanterior cephalograms are subject to all of the errors associated with cephalometrics, substantial limitations arise from internal orientation error associated with variations in the three-dimensional position of the head relative to the instrumentation.

As a research tool, cephalometry has been the most widely used imaging modality in orthodontic investigations. Cephalometry has been used to quantify craniofacial parameters in individuals or sample populations, to distinguish normal from abnormal anatomy, to compare treated and untreated sample populations, to differentiate homogeneous from mixed populations, and to assess patterns of change through time.[6]

Panoramic Projections. Panoramic imaging is an excellent technique if used with the realization that it has greater value for screening than for diagnostic purposes. Panoramic radiographs provide some information about mandibular symmetry; present, missing, or supernumerary teeth; dental age; eruption sequence; and limited information about gross periodontal health, sinuses, root parallelism, and the TMJs. A panoramic projection also can reveal to some degree the presence of pathologic conditions and variations from normal. A point to stress, however, is that panoramic radiography has many shortcomings related to the reliability and accuracy of size, location, and form of the images created. These discrepancies arise because the panoramic image is made by creating a focal trough or region of focus to conform with the generic jaw form and size. Panoramic projection provides the best images when the anatomy being imaged approximates this generic jaw. However, any deviations from this generic jaw form result in a structure that is not centered within the focal trough, and the resultant image shows differences in size, location, and form compared with the actual object[11] (Figure 4-2). In addition to the mismatch between panoramic focal trough and the imaged anatomy, the variations in horizontal and vertical x-ray beam angulations can lead to a false perception of the anatomic truth. A relevant clinical example of this phenomenon can occur when the panoramic projection is used to evaluate mesiodistal angulations or alignment of adjacent roots. The dental areas most susceptible to false interpretation of root alignment include the regions between the canine and first premolars in both arches and between the mandibular canines and the adjacent lateral incisors.[17]

Periapical Projections. The periapical projection series consists of bitewing and periapical projections. More controversy surrounds the routine use of this series than perhaps any other radiographic method used in orthodontics. One should give serious consideration to the cost-benefit ratio, taking into account the radiation exposure, diagnostic value, and the need for medicolegal documentation. Selection of this imaging technique generally is recommended on a case-by-case basis because the potential risks from ionizing radiation are significant.[6] There are many indications for the use of these radiographs, particularly in adult patients to assess periodontal status and root morphology and length. However, in most of these cases a limited series often proves to be the most prudent choice. Communication with the general dentist is advisable to select the most appropriate time, series, and sharing of periapical and bite-wing radiographs. From a strictly orthodontic perspective, these images provide several benefits, including the ability to assess overall dental and periodontal health; root length, shape, and form; presence of periodontal ligament space to help rule out the possibility of ankylosis; positions of impacted or erupting teeth; and root parallelism. Periapical radiographs also are used along with some mixed dentition analyses.

Tomography/Computed Tomography Scans. *Tomography* is a general term used for an imaging technique that provides an image of a layer of tissue.[18] These layers or planes can be oriented to conform to a desired slice of the anatomy under study. The versatility of this technique makes tomography highly desirable for accurate imaging of a wide variety of maxillofacial structures, including that of the TMJs and for cross-sectional imaging of the maxilla and mandible. Modern complex-motion tomographic units can be optimized to image any selected region of the facial skeleton.

Corrected Tomography of the Temporomandibular Joint. Axially corrected tomography has been a commonly used technique to examine the hard tissue of the jaw joint and to assess the open and closed mouth

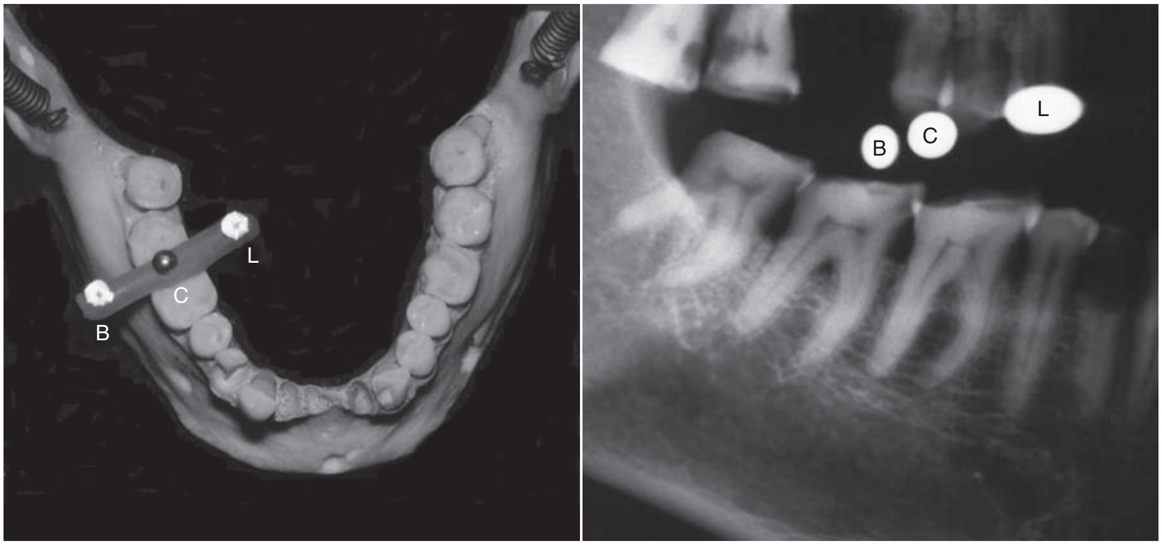

FIGURE 4-2 **A,** The spherical lead markers are positioned parallel to the contact region of the molars and perpendicular to the "focal trough." The lead markers are marked buccal *(B)*, center *(C)*, and lingual *(L)*. In the resultant panoramic image **(B)**, note the differences in size, location, and form of these round spheres. The buccal marker *(B)* is foreshortened and projected distally and inferiorly. The lingual marker *(L)* is elongated and projected mesially and superiorly. If the "generic focal trough" of the panoramic unit does not match the patient's anatomic focal trough, distortions will result in the resultant panoramic image. Therefore, significant differences may occur in the analysis of root angulations, parallelism, size, location, and form.

condyle-fossa spatial relationships. Axially corrected TMJ tomography refers to the alignment of the tomographic beam with the mediolateral long axis of the condyle to produce image layers that are parallel or perpendicular to the mediolateral long axis of the condyle. The laterosuperior and mediosuperior surfaces of the condyle are more difficult to image than the central two thirds of the condyle with sagittal tomography, and axially corrected coronal plane images therefore are recommended for viewing these surfaces.[11] The value of this technique is limited because it provides a two-dimensional image and because of its inability to image the disk.

Soft Tissue Imaging

Corrected Tomography of the Temporomandibular Joint. CT differs from traditional tomography by the use of a computer to aid in generating the image and by allowing multiple CT slices to be "stacked" to represent a three-dimensional form. CT, although better than traditional radiography, is inefficient at producing suitable soft tissue contrast because it is designed and optimized for visualization of hard tissues. Depending on the operational settings of the CT and the visualization software, some soft tissues such as the skin surface can be seen. If the primary imaging goal is soft tissue imaging, other imaging modalities may be more appropriate.

Magnetic Resonance Imaging. Imaging of the soft tissues in and around the TMJs using MRI has coincided with and created interest in the function and biology of the TMJ. Because x-ray–based imaging, including CT scans and tomograms, is unable to show intraarticular soft tissues adequately, MRI is the preferred imaging technique when information regarding the articular disk, presence of adhesions, perforations, or joint effusion is desired. MRI has the advantage of creating an image without using ionizing radiation, without pain, and without distorting tissues, but its use is not widespread in orthodontics because of limited access to dentists and its expense.

Imaging can be performed in any plane of space, and therefore the acquisition techniques can be optimized to the anatomy. Variations in MRI protocols and the use of paramagnetic contrast enhance the signal contrast between adjacent tissues. T2-weighted protocols (long echo time and long repetition time) are used routinely to determine joint effusion and inflammation, changes in bone marrow caused by sclerosis, inflammation, and other tissue replacement processes. T1-weighted protocols (short echo time and short repetition time) are used to determine disk–condyle–fossa position, morphology, internal composition, and mobility. Recently, MRI spectrometry and functional and dynamic MRI have been used to supply clinical information about jaw function.[19]

Interpretation of MRI has been able to achieve 90% or greater accuracy in the identification of condylar erosions, osteophytes, and flattening and disk position.[20] Tissue contrast is created using a range of protocols (pulse sequence) extending from T1 to T2 weighting. The resultant grayscale images represent the recorded signals from the pulsed tissues with the high signal appearing white, intermediate signals appearing gray, and low signals or signal voids appearing black. The T1- and T2-weighted protocols produce tissue signatures as shown in Table 4-1.

Arthrography. Arthrography relies on radiographic image acquisition following the intraarticular administration of an iodinated contrast agent. The contrast is placed transcutaneously under fluoroscopic guidance. Arthrography has contributed greatly to the understanding of disk position, but in recent years MRI has reduced the number of arthrograms performed on the TMJ. Arthrography has an advantage over MRI of dynamic visualization, in identifying the presence of the perforations between the superior and inferior joint compartments and adhesions but has the disadvantages of increased patient risks related to radiation dosage, percutaneous injection into the TMJ, and potential for allergic reaction. In many patients, there is a "therapeutic effect" with the arthrogram as the injection of saline and cortisone has a lubricating effect, as with "arthrocentesis."

CONTEMPORARY AND EVOLVING IMAGING TECHNIQUES

Digital Imaging

A variety of digital imaging technologies exist for craniofacial imaging. The technologies are designed for imaging specific tissues, such as the face, skeleton, and muscles. In general, these technologies can be noninvasive by using magnetic resonance, ultrasound, visible light, and laser or invasive using radiography. The initial digital imaging technologies adopted by the orthodontic profession included photography, panoramics, cephalometrics, and periapical imaging. Replacement

TABLE 4-1 Magnetic Resonance Image Signal Intensity Expected for T1- or T2-weighted Protocols

Anatomic Feature	T1-Weighted Protocols	T2-Weighted Protocols
Air	Low	Low
Cortical bone	Low	Low
Blood vessels	Low	Low
Bone marrow	Bright	Low
Muscle	Intermediate	Intermediate
Fat	Bright	Low
Disk	Low	Low to intermediate
Fluid	Intermediate	Bright

of film-based imaging with digital imaging creates the potential to increase productivity, improve quality, reduce x-ray dose, and reduce regulatory burdens. Incorporation of digital processes into the customary work flow of a clinical practice also may require infrastructure changes and integration of the digital equipment into an existing office network. The specific uses of these digital technologies for craniofacial imaging are described next.

Volumetric Imaging. Volumetric imaging is synonymous to three-dimensional imaging because the information has depth and length and width. Within this domain are x-ray (CT and cone beam CT [CBCT]) and MRI technologies.[21]

Computed Tomography. CT examination is one of the most valuable medical imaging modalities available. Use of CT in the United States rose from 5.5 million examinations in 1983 to more than 20 million in 1995. CT examinations comprised about 2% of all radiographic examinations in 1991 and in 2001 comprised 10% to 15% of the total. Despite significant advances in other aspects of CT technology, the radiation dose has remained essentially unchanged.[22] For this reason and for those associated with cost, access, and training, the use of traditional CT examination in dentistry has remained low and is restricted primarily to craniofacial anomalies and comprehensive treatments. However, this situation is evolving rapidly with the advent of CBCT for dentistry.

Cone Beam Computed Tomography. The two principal differences that distinguish CBCT (also known as cone beam volumetric tomography [CBVT]) from traditional CT are the type of imaging source–detector complex and the method of data acquisition. Figure 4-3 illustrates the basic difference between these two

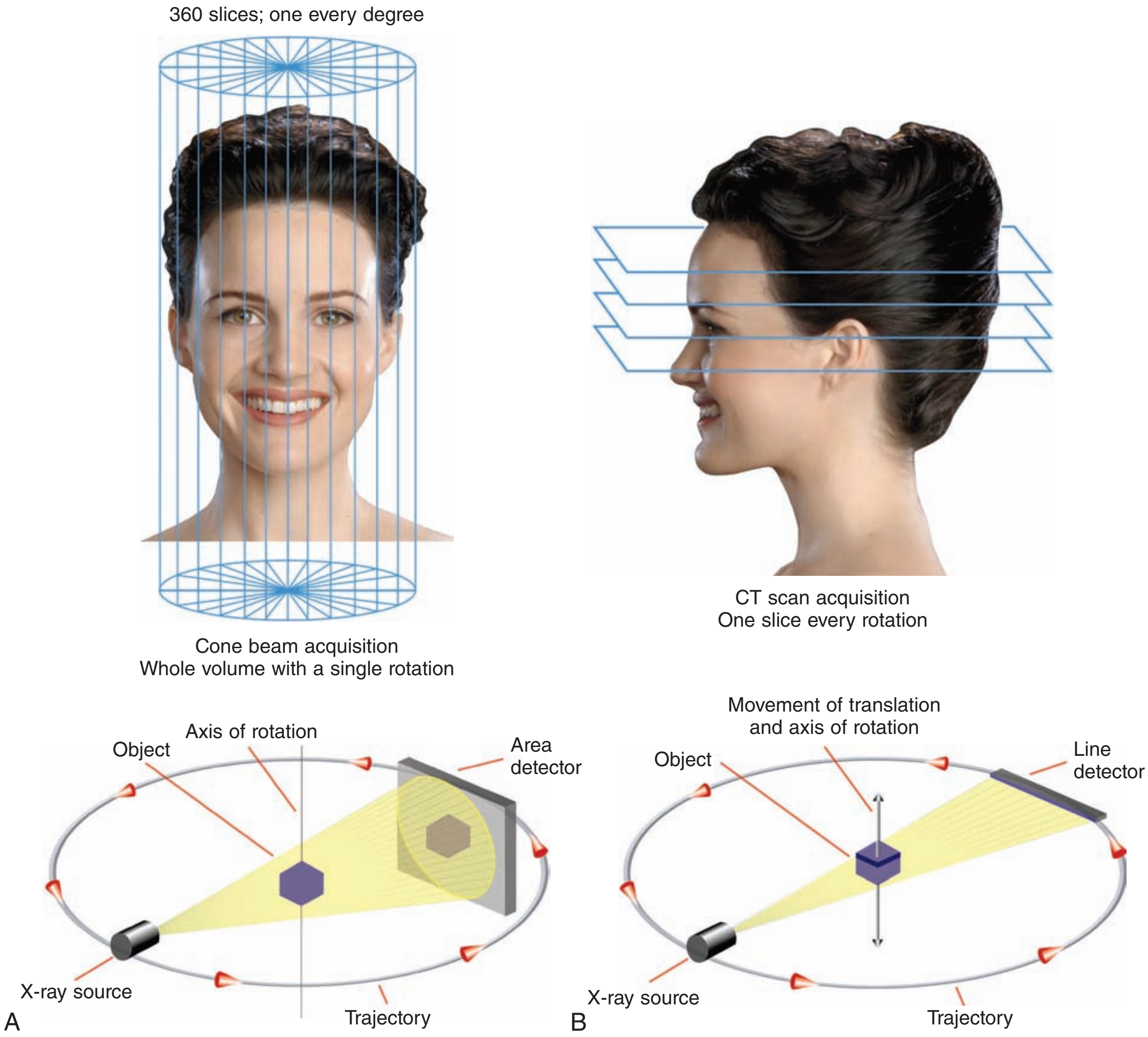

FIGURE 4-3 The main differences between cone beam computed tomography (CT) **(A)** and traditional CT **(B)** are the type of imaging source–detector complex and the method of data acquisition. *(Image courtesy of Drs. Ivan Dus and Carl Gugino, Aperio Services, Inc, Sarasota, Florida, from Mah J, Hatcher D: Three-dimensional craniofacial imaging,* Am J Orthod Dentofac Orthop *126(3):308–309, 2004.)*

technologies. The x-ray source for CT is a high-output rotating anode generator, whereas that for CBCT can be a low-energy fixed anode tube similar to that used in dental panoramic machines. CT uses a fan-shaped x-ray beam from its source to acquire images and records the data on solid-state image detectors arranged in a 360-degree array around the patient. The CBCT technology uses a cone-shaped x-ray beam with a special image intensifier and a solid-state sensor or an amorphous silicon plate for capturing the image.[21,23,24] Development of this technology dates back to the mid-1970s when it was originally devised as a cost-effective and efficient method for obtaining cross-sectional three-dimensional images for radiotherapy and later for angiography.[25–27]

Conventional medical CT devices image patients in a series of axial plane slices that are captured as individual stacked slices or from a continuous spiral motion over the axial plane. Conversely, CBCT presently uses one or two rotation sweeps of the patient similar to that for panoramic radiography. Image data can be collected for a complete dental/maxillofacial volume or limited regional area of interest. Scan times for these vary from approximately 5 to 90 seconds. Doses can be as low as 40 mSv to 50 mSv values[28,29] in a range similar to that of conventional dental radiographic examinations.[22] In comparison, the effective radiation dose from a panoramic examination[30] is in the range of 2.9 to 9.6 mSv and that from a complete mouth series[30,31] ranges from 33 to 84 mSv and 14 to 100 mSv. A dental examination using medical CT for the purposes of implant placement results in effective doses of 30 to 650 mSv depending on the examination area, machine settings, slice thickness, and other variables.[32] From the perspective of radiation dosimetry, CBCT is much welcomed because the radiation dose from medical CT has not decreased in the past decade, whereas the radiation doses from other forms of medical radiography have decreased by 30%.[22]

The next advancement in dental imaging is the acquisition of multiple image views, various measurement analysis, and computer-generated patient models that will allow the diagnostician to visualize better in a "spatial plane concept" the potential therapeutic procedures before actually rendering them. Figures 4-4 and 4-5 show example images obtained from CBCT. Figure 4-4 shows a composite of the representative images. Many different image views of the patient are possible. "If a picture is worth a thousand words," then what is a multidimensional model worth? At 1-degree increments, in all three planes of space, it would be worth 360 × 360 × 360, or 46,656,000 pictures! (Many more if you consider fractions of degrees.) Although the common panoramic, implant, and TMJ views are present (Figure 4-4, *A–C*), the volumetric reformatting (Figure 4-4, *D–G*) represents a new dimension in imaging. Figure 4-4, *D*, reveals a mandibular third molar and its relationship to the inferior alveolar canal; Figure 4-4, *E*, is a cross-sectional arch view; and Figure 4-4, *F* and *G*, are representative of the many possible airway images. Each of these images is only one of many that comprise the three-dimensional volume for any anatomic area being examined. In addition, computer-generated models can be reconstructed from the initial imaging data; examples are shown in Figure 4-5, *A–D*. The posterior palatal-lingual view, not readily available with traditional dental radiography, is demonstrated in Figure 4-5, *B*. Views from the posterior are unique to volume imaging and offer the possibility to replace stone models for this function. (For a related case study, please go to www.orthodontics-principles-techniques.com.)

Structured Light. The principle behind structured light systems is the projection of a pattern onto a surface that is distorted and interpreted as three-dimensional information to produce a surface map. Patterns that are used vary from lines, stripes, grids, circles, and other designs. An example of this is the basic system from Eyetronics that uses a 35-mm slide projector to project a grid pattern and a common digital camera to record images (Figure 4-6, *A–C*). Because these systems capture images from only one perspective or camera viewpoint, several images are taken to obtain frontal, left, and right views of a face. To produce a full-face model (from ear to ear) with these systems, different perspectives are combined in a process called stitching to produce one model (Figure 4-6, *D–F*). Stitching can be performed manually or semiautomatically if the user selects common correspondences between the perspectives to be combined. Developments are underway to improve and automate this process because it is time consuming and at present requires manual intervention to obtain satisfactory results.

Because a pattern is projected onto the face, the texture map (color information) contains this pattern information and can be distracting. For this reason, a second image often is taken with the subject in the identical position without the projected pattern. In this way, the surface map, derived from the projected pattern, is used with a clean texture map to produce more realistic three-dimensional images. However, at this time only one of these structured light imaging systems has been validated for clinical use.[33]

Laser Scanning. Another popular technology for three-dimensional facial imaging involves the use of lasers. Laser scanners are capable of producing detailed models; however, the scanning process requires the subject to remain still for a period of seconds to 1 minute or longer while the scanner revolves around the subject's head. Because the laser provides only the surface map and cannot provide color information for the texture map, a color camera that is registered with the laser scanner provides this information.

In studies of laser scanning of inanimate objects, such as plastic and plaster mannequin heads, investigators reported a 0.6-mm variance of localization in the three axes (*x*, *y*, and *z*) when using prelabeled anthropometric landmarks.[8] Reports on the accuracy of laser imaging

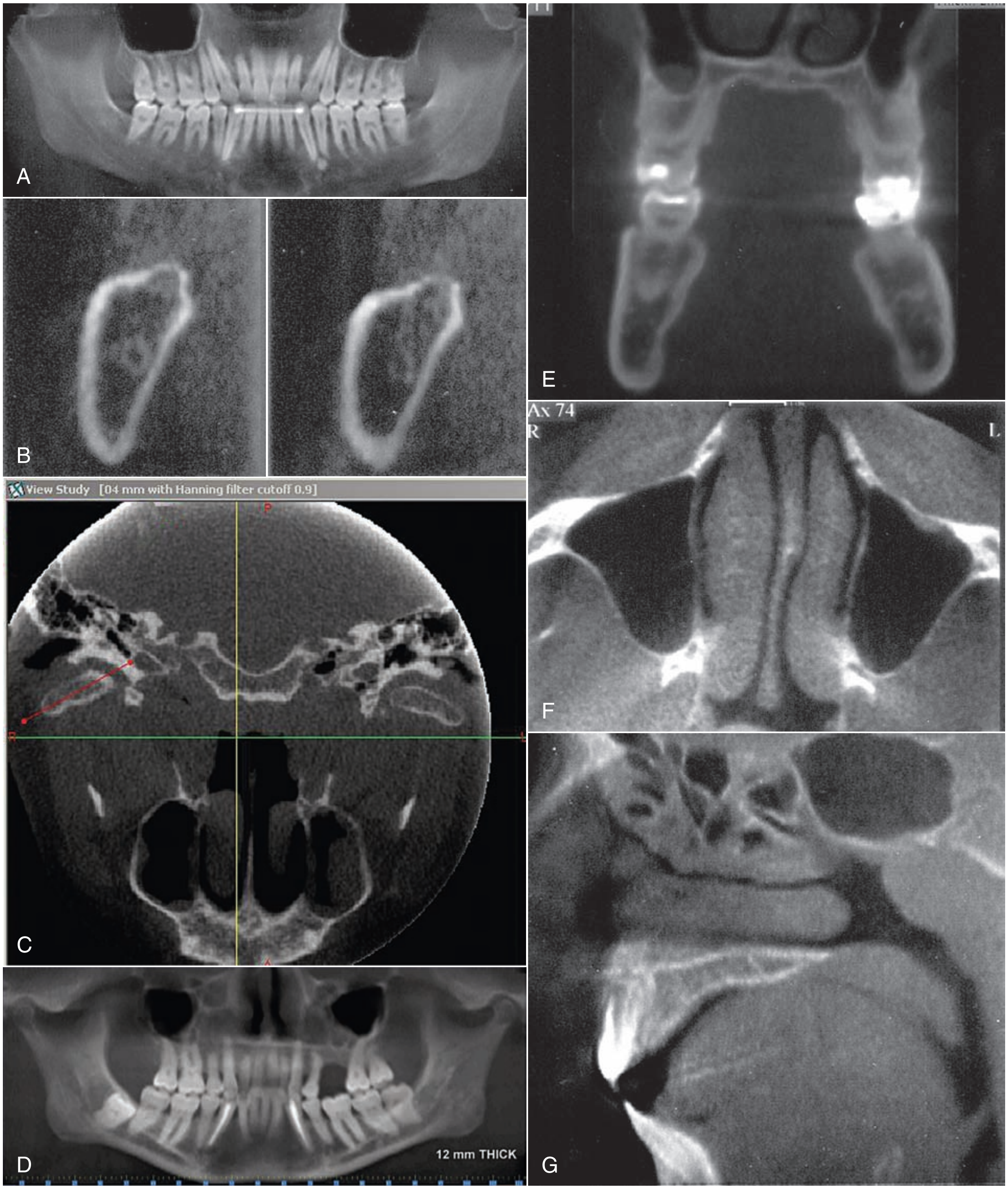

FIGURE 4-4 Many different image views of a patient are possible with cone beam volumetric tomography. **A,** Common panoramic view. **B,** Implant. **C,** Temporomandibular joint view. **D,** Mandibular third molar and its relationship to the inferior alveolar canal. **E,** Cross-sectional arch view. **F, G,** Examples of the many possible airway images.

using another design of laser scanner showed that the reported precision of the laser scanning device is about 0.5 mm.[6,11,34] However, more comprehensive studies using laser systems for anthropometric measurements reported that more than half of these were unreliable (errors greater than 1.5 mm).[35]

Stereophotogrammetry. Similar to the human visual process, stereophotogrammetry uses two images separated in viewpoint by a small distance. The images from human eyes are interpreted by the brain to provide images with depth. This cooperative process was described using dot stereograms almost 45 years ago.[4]

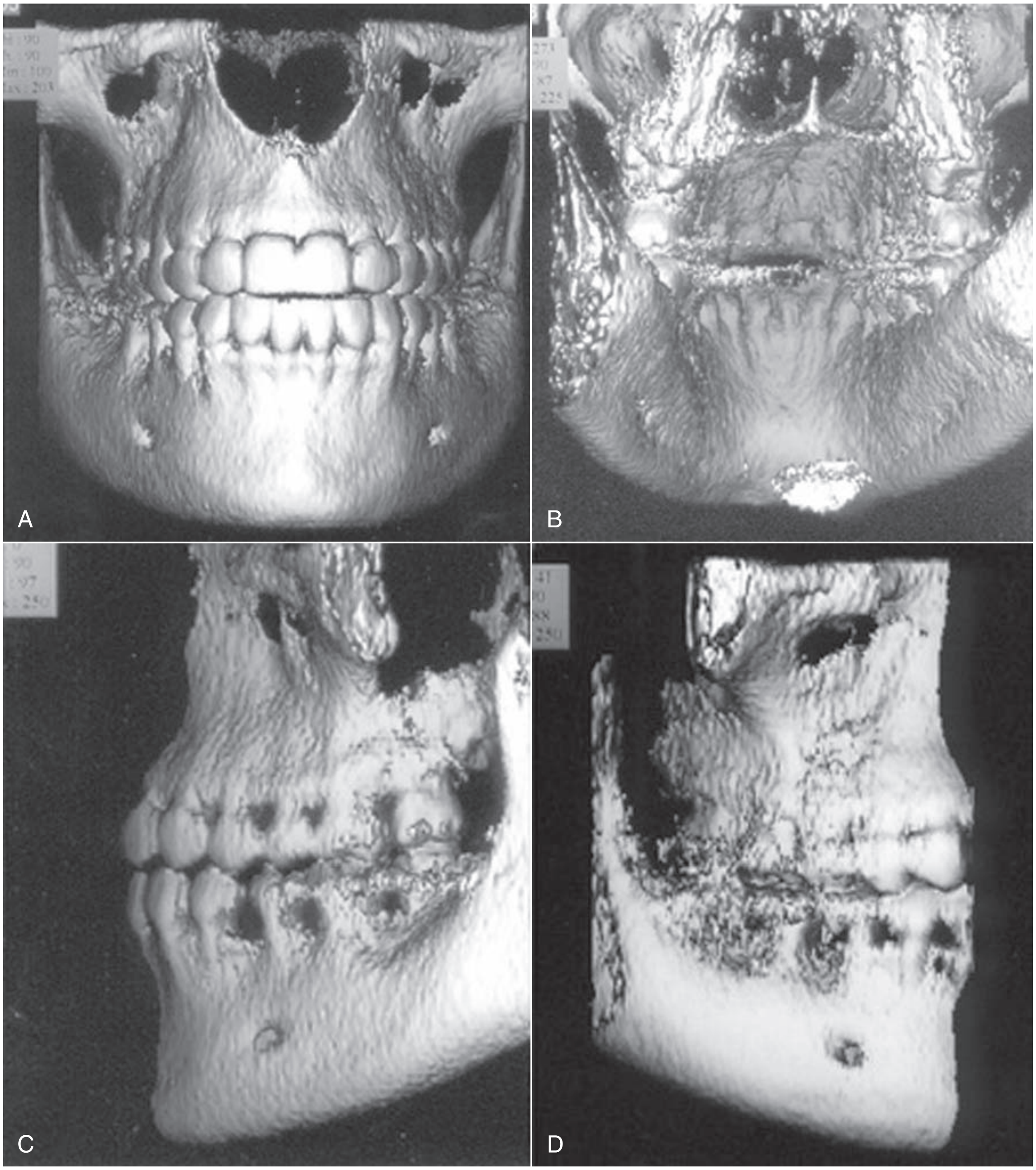

FIGURE 4-5 **A–D,** Examples of computer-generated models reconstructed from the initial imaging data. **B,** Posterior palatal/lingual view, not readily available with traditional dental radiography.

Other developments in this area include algorithms for stereo reconstruction.[36] The use of stereophotogrammetry for craniofacial imaging has been reported using dry skulls,[37] cleft lip and palate,[38] and for quantification and validation of the linear and angular facial measurements.[10,39] In the latter, the absolute value of the reproducibility error for localizing the landmarks reported is 1 mm for distance and 1.1 degrees for the angles.[10] More recently, stereophotogrammetry with two infrared charge-coupled device cameras was used to locate facial landmarks automatically (labeled with retroreflective markers) and provide anthropometric information (linear distances and angles).[29,32,33,40] The error in reproducibility of a landmark and marker location was less than 2 mm (Figure 4-7).

Current Status of Three-Dimensional Facial Imaging

Acquiring dimensionally accurate facial images using any of the foregoing approaches is demanding because of tissue reflectance, interference of hair and eyebrows,

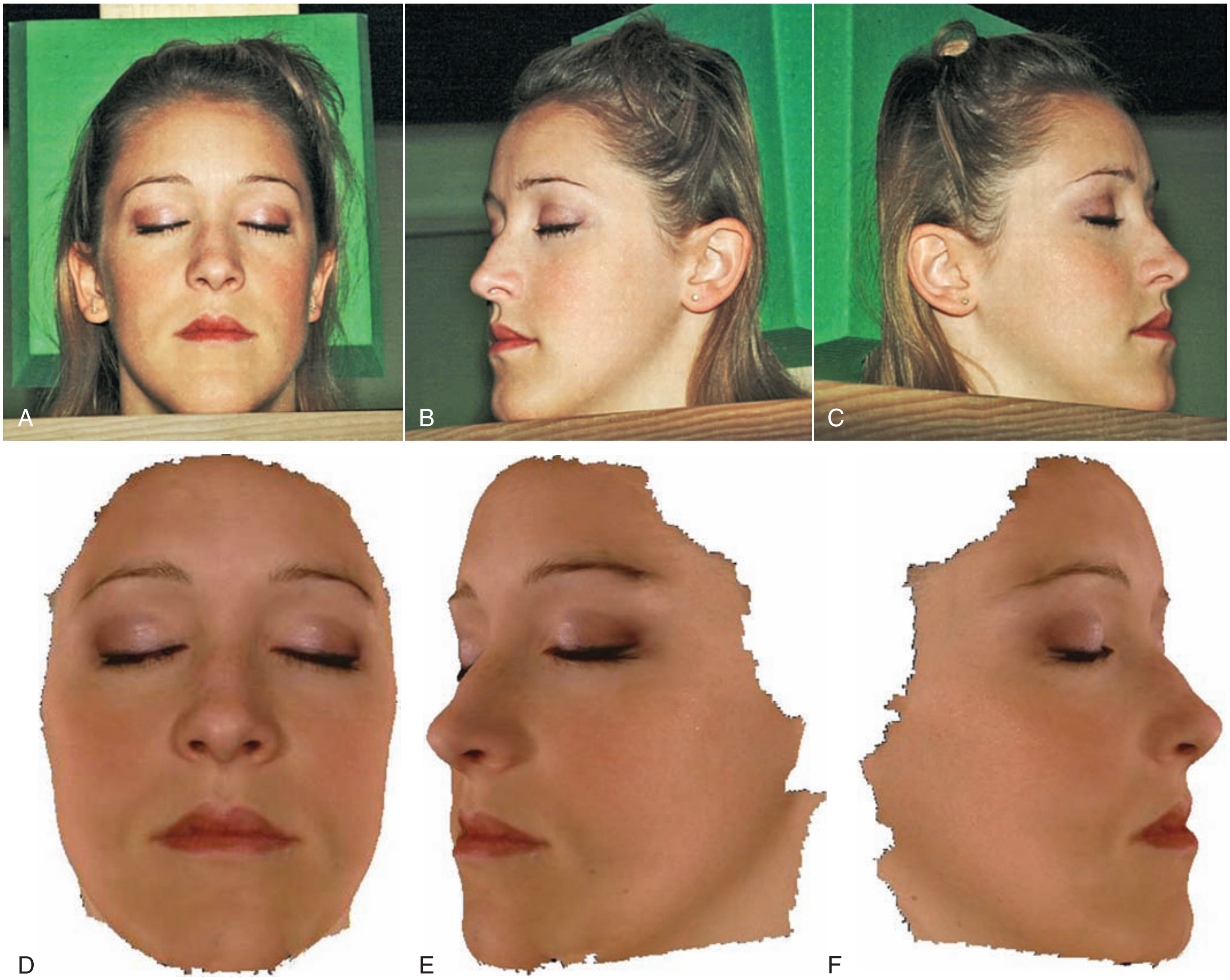

FIGURE 4-6 Structured light imaging. **A–C,** The basic system from Eyetronics uses a 35-mm slide projector to project a grid pattern and a common digital camera to record images of front and side angles of the face and create a surface map. **D–F,** Different perspectives are combined in a process called stitching to produce one model.

change of posture between different views (if needed), and movement during imaging (more so with lasers because of longer exposure times). Additionally, certain structures such as eyes and ears do not image well because of extreme reflectance or undercuts where light and lasers cannot access. Compounding these is the postprocessing complexity during which the computer processes these images to reduce artifacts and smooth surfaces while retaining detail. In addition, errors are introduced during the stitching together of the multiple perspectives to form a complete facial model. Furthermore, although anthropometric standards are available,[41] methods of three-dimensional facial analysis are lacking. Given these limitations and others, no system is in common clinical use, although there are ongoing developments and technologies to eliminate these limitations.

Dental Crowns

The two general approaches to producing three-dimensional models of the dental crowns are direct and indirect methods. The latter begins with an alginate impression or, for more accuracy, a polyvinyl siloxane impression. The impression is poured with plaster or stone and imaged in a destructive or nondestructive manner. Destructive imaging involves the removal of a thin layer of material, alternating with image capture to generate a stack of images that are rendered in three dimensions. Nondestructive imaging involves the use of a laser-based system with a multiaxis robot to obtain several perspectives of the plaster model (Figure 4-8). The perspectives are combined to render a complete model. Another approach to nondestructive scanning involves the use of CT methods to image the plaster

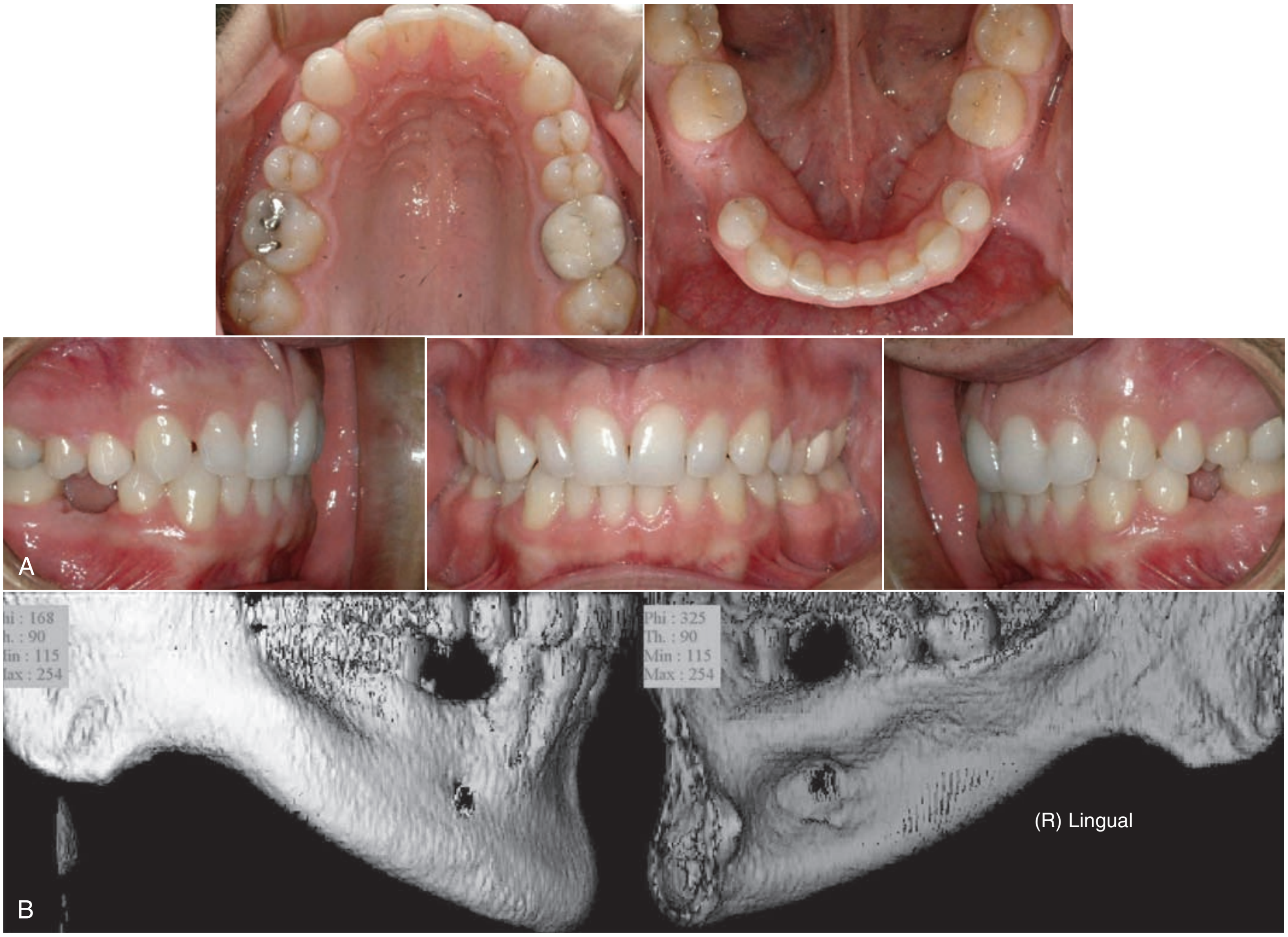

FIGURE 4-7 Presurgical implant workup using a NewTom 9000 cone beam computed tomography scan. **A,** Clinical photographs showing bilaterally missing mandibular second premolars and the potential space for implant placement. **B,** Shaded-surface rendering showing the buccal and lingual views of the right half of the mandible. This view allows for visualization of a large lingual fossa.

model or alternatively to image the dental impression directly (Figure 4-9). Within these processes are the abilities to generate models with qualitative and semiquantitative information and models that are dimensionally accurate for production of dental appliances; for example, the Invisalign (Align Technology, Santa Clara, Calif) appliance or patient-specific orthodontic brackets (Incognito from 3M Unitek [Monrovia, CA], Insignia from Ormco [Glendale, CA]).

Several direct imaging methods for producing three-dimensional models of the dentition have been introduced. In general, an intraoral camera is used to image small regions of the dentition, which are subsequently rendered as a model (Figure 4-10). After isolation of the dentition and application of an opaquing agent, small postage stamp–sized images of the dentition are taken with a video camera while a pattern is projected onto the teeth. The images are transmitted to a computer, where they are registered, and the data are processed to remove artifacts and redundant points. The complete dental arch can be imaged in about 90 seconds; however, actual times of imaging may be much longer depending on several patient and operator factors.

After imaging, models of the dentition are produced for diagnosis and treatment simulation/planning. For diagnostic purposes, the entire arch can be treated as a single object; however, for treatment simulation, particularly involving tooth movement, the single arch must be segmented into individual teeth. Because the contact points between teeth do not image well, segmenting the teeth is a formidable challenge.

Tooth Roots

Traditional methods to obtain tooth root information use panoramic or periapical radiographs. Although these images yield useful information on root morphology and relative relationships such as root positions, the

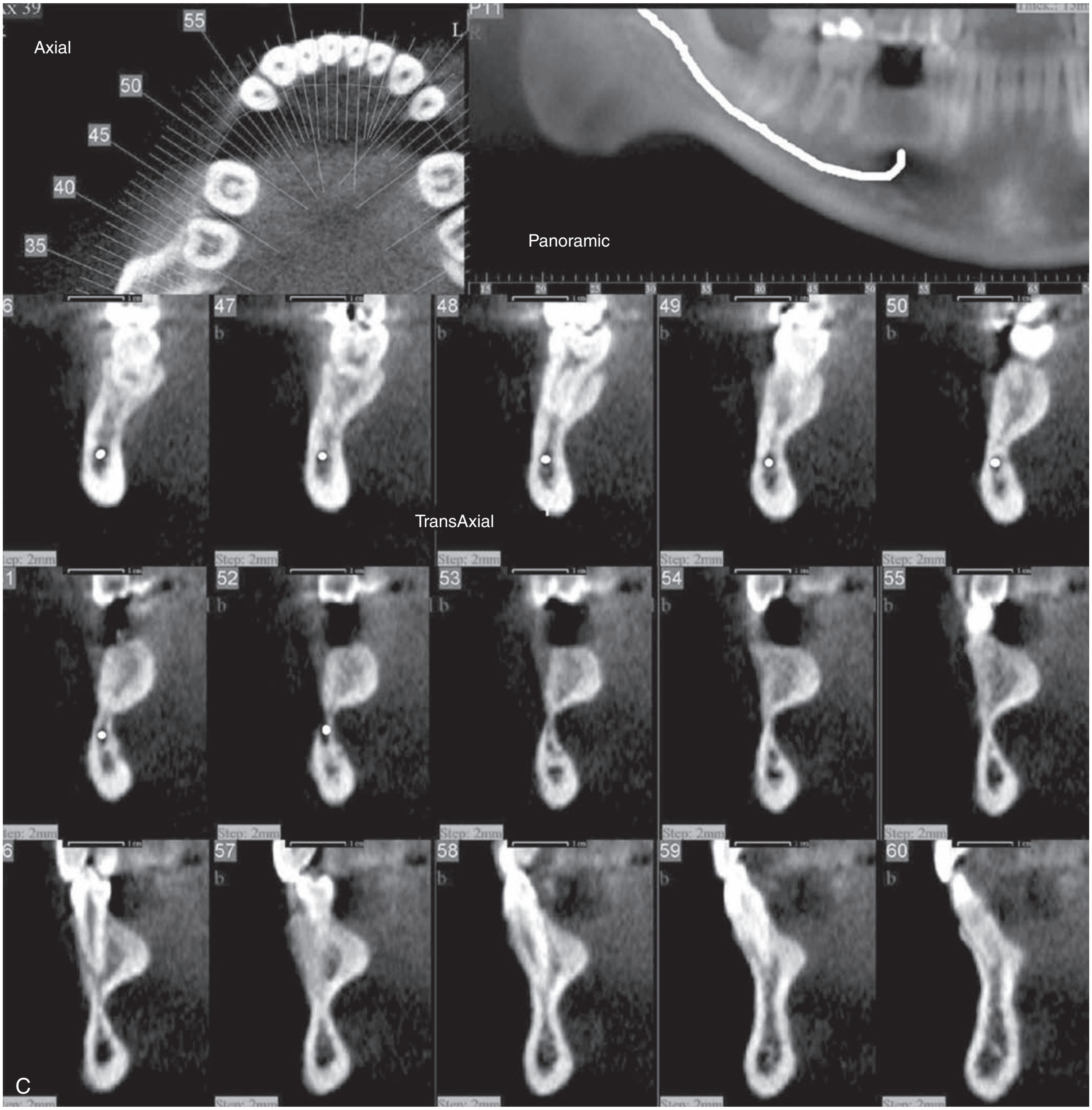

FIGURE 4-7, cont'd **C,** A sequence of spatially cross-referenced images of the mandibular right side. The mandibular canal has been marked (*white overlay*). The *top left* image is an axial view showing the dentition and is marked with transaxial reference lines. The *top right* image is a panoramic reconstruction of the right half of the mandible showing the dentition, supporting bone and marked mandibular canal. The *bottom* panels of images are the transaxial views numbered to correspond with axial and panoramic views. The transaxial views are a buccolingual cross-sectional view. The transaxial views allow for the localization of the mandibular canal, determination of the bone height and width in proposed implant site, visualization of lingual fossa, and assessment of bone quality.

information is two-dimensional and subject to projection errors. In a recent study on the use of panoramic images to assess root parallelism, researchers found variation between different panoramic devices and that the majority of image angles from panoramic units were statistically significantly different from the true angle measurements and concluded that the clinical assessment of mesiodistal tooth angulation with panoramic radiography should be approached with extreme caution.[17] Three-dimensional root information is necessary for comprehensive

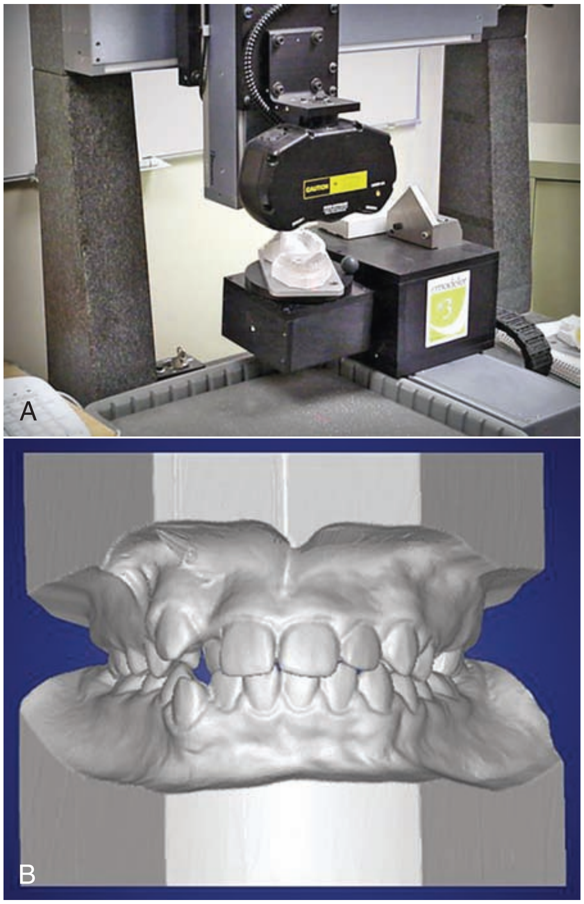

FIGURE 4-8 In nondestructive imaging, a multiaxis robot scans the surface of a plaster study model by using laser imaging technology **(A),** which is then used to render a complete model **(B).** *(Courtesy GeoDigm Corporation, Chanhassen, Minn.)*

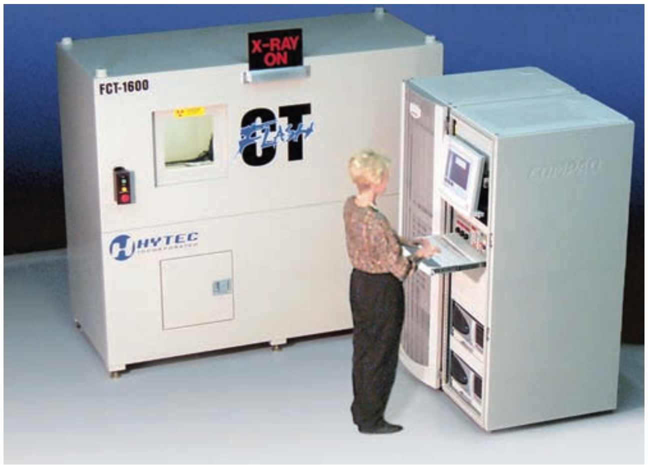

FIGURE 4-9 Computed tomography methods also can be used to image the plaster model or to image the dental impression directly. *(Courtesy HYTEC Inc., Los Alamos, NM.)*

patient-specific models. Currently, three-dimensional models of dental crowns are used for treatment planning and appliance production; however, the dentition is incomplete without the root structure. This information can be obtained from conventional CT or CBCT.

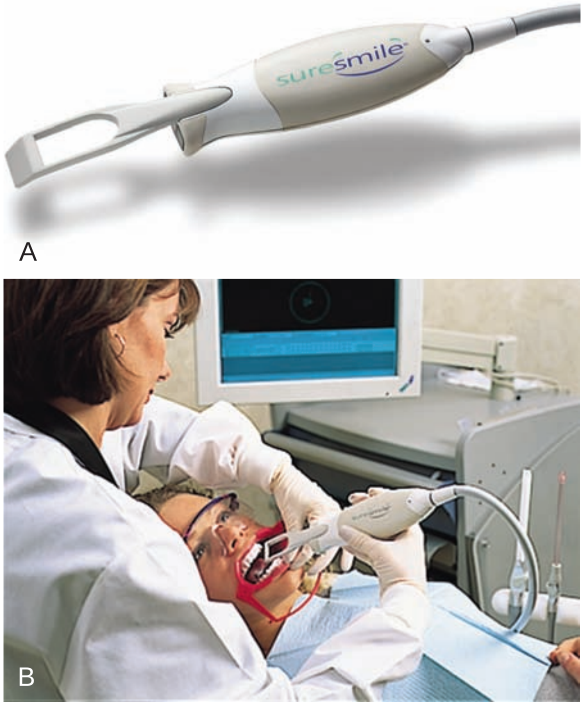

FIGURE 4-10 The SureSmile system is based on structured light principles. **A,** An intraoral camera used to produce images for three-dimensional modeling. **B,** After isolating the dentition and application of an opaquing agent, small postage-stamp–sized images of the dentition are taken with a video camera while a light pattern is strobed onto the teeth. *(Courtesy OraMetrix, Inc., Dallas, TX.)*

The tooth roots reside within the volume and need to be separated or segmented out of the volume to produce independent objects for treatment simulation and therapy purposes (Figure 4-11). The processes to perform this function are currently under development. In addition, the root information needs to be integrated with the highly accurate three-dimensional dental crown information (Figure 4-12).

IMAGE CALIBRATION AND REGISTRATION

Visualization and reconstruction of craniofacial anatomy are integral to understanding biomechanical relationships in the face and jaws. Computer-assisted imaging is creating the opportunity for the orthodontic profession to better visualize and study the craniofacial anatomy. New imaging tools allow for accurate three-dimensional replication of the patient in the form of a "patient-specific anatomic reconstruction" (PSAR).[42,43] The PSAR can be used to assess the craniofacial and dental anatomy in static and dynamic states. New interactive imaging tools allow the orthodontic practitioner to manipulate the PSAR to simulate treatment and dynamically test feasibility of various treatment approaches. PSARs can be used to study and simulate the functional

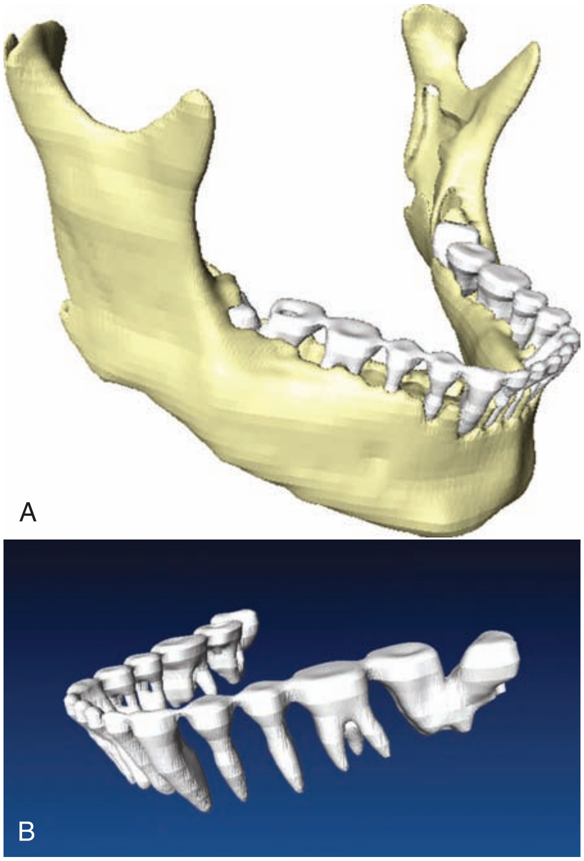

FIGURE 4-11 Three-dimensional models of dental crowns. **A,** In volumetric tomography, tooth roots reside within the scanned volume. **B,** Roots can be separated out for treatment planning purposes.

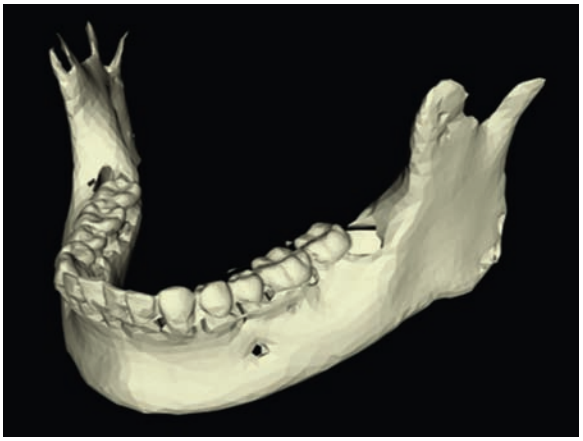

FIGURE 4-12 Root information can be integrated with the highly accurate three-dimensional dental crown information to form a full, merged image for comprehensive patient-specific models.

relationships between various tissues. The knowledge gained through simulation can be used to assist the practitioner during the clinical phase of treatment. New imaging technology, when appropriately used, will improve treatment efficacy and efficiency.

The "best source image data" for each type of anatomy being modeled is calibrated and coregistered to the same three-dimensional matrix. The image modes used to create a model are included in Table 4-1. The measurements can be used to construct models, spatially stitch (or "coregister" may be better word than "stitch") together various image sets, and populate a morphometric database with three-dimensional locations of selected anatomic structures.

When data from two- or three-dimensional image sets are combined into a three-dimensional matrix, they are assigned concurrently a common Cartesian coordinate system. To create the model, the relevant anatomy displayed in the images is reduced to a point cloud with each point being numerically described on the Cartesian coordinate system (x, y, z). The points then are connected with lines and are transformed to vertices on a polygon mesh. The polygon mesh is tiled, smoothed, and textured to create a realistic rendering of the anatomic surfaces. The polygon mesh is segmented into anatomically relevant objects, such as maxilla, mandible, and teeth. Splines or surface subdivision techniques are among other available rendering options. Once a PSAR is generated, it can be enhanced to create a "smart model" by providing the anatomic objects with attributes. For example, the viscoelastic tissue properties and specific landmarks may be linked to a morphologic database.

Multiple calibrated images permit simultaneous three-dimensional measurements of selected anatomic structures. Knowledge of the spatial relationships between the source, sensor, and the imaged anatomy with 7 degrees of freedom (x, y, z, yaw, pitch, roll, and focal length) creates the ability to combine multiple images into a three-dimensional database for future analytic or reconstruction procedures. Analysis of images in a calibrated environment creates the opportunity to extract accurate craniofacial three-dimensional morphometric data. A calibrated environment is a three-dimensional, true and accurate visualization and analysis space (or volume) where all modes of diagnostic bioimaging can be calibrated, coregistered, and correlated, and simultaneously viewed and analyzed. The calibrated environment overcomes the significant shortcomings of multiplane radiographic images and photographs through the calibration and coregistration process to enable accurate three-dimensional measurements.[44,45] Accurate morphometric data have great value in developing a database of craniofacial form and to initiate cross-sectional and longitudinal studies in growth, development, and therapeutic interventions and outcomes. The calibrated environment has the potential to advance global knowledge and education relative to craniofacial anatomy. The transformation of the two-dimensional cephalometric images within the calibrated environment will overcome their shortcomings frequently enumerated in the clinical and research communities.*

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*References 7, 13, 35, 39, 44–50.

The craniofacial models are composed of multiple anatomic objects that have a hierarchic relationship to each other and possess a local coordinate system. The anatomic objects for the craniofacial models include teeth with roots, maxilla with skull, mandible, and facial soft tissues. The image modes to be imported into the calibrated environment to create the PSAR include cephalometric projections, CBCT, and structured light images of the tooth crowns and stereophotogrammetry of the face.

DATABASE

Craniofacial imaging database programs currently in clinical use are designed primarily to be an image management system for storage, retrieval, and viewing of two-dimensional patient images. Two examples are Dolphin Imaging (www.dolphinimaging.com) and Quick Ceph Systems (www.qceph.com/index.html). These systems allow for two-dimensional measurements on uncalibrated and uncorrelated images for the purpose of orthodontic assessment.

Several sources of error are known to occur in the standard two-dimensional cephalometric measurement techniques. The measurements guide the clinician in devising a plan to transform the size, shape, location, and orientation of the teeth, jaws, and adjacent facial soft tissues. These measurement files are stored in the patient record and not pooled with the data from other patients. These techniques are time consuming and highly dependent on operator interaction.[33,46,51] The computer in the foregoing scenario does provide some advantages by containing algorithms for computing angles and distances between landmarks and allows for rapid editing of landmark location. At this level of involvement, the computer acts as an electronic bookkeeper equipped with certain measurement capabilities. A higher level of computerized assistance would require that part of the analysis be performed by the computer. Such a level can be accomplished by having algorithms automatically locate landmarks in the images through the use of filtering, contrast enhancement, edge detection, image processing, and artificial intelligence. Some have made attempts and in some cases actually have used computer-aided recognition of cephalometric landmarks; however, the problem of identifying landmarks is nontrivial.†

The problem is a mixed detection, recognition, and estimation problem,[59] and its solution must contain “a priori knowledge” about the relevant features. Because anatomic shapes can vary between individuals, localization of such shapes requires more sophisticated approaches than simple template matching. von Seelen and Bajcsy[20] noted that template matching is invariant to translation, but the template correlation is generally not strong when the scale or orientation of the template and image varies. Although collections of scaled and rotated versions of templates could be used, such an approach can become processing intensive, especially if an exhaustive collection is used. CBCT of the craniofacial region has been introduced into clinical practice. This technique automatically solves the association problem by radiographic sampling of a large number of small-angle increments around the head. This technique provides a rich source of anatomic voxel data for clinical applications.[60]

A necessity exists to develop an open standard database that can store multiple source modes of calibrated two- and three-dimensional bioimages, analysis data, and simulation models and maintain current statistical data. An active database software function currently is under development that will enhance the patient-specific anatomic model by automatically identifying anatomy and associated landmarks, perform volumetric analysis characterizing each individual tooth and other craniofacial components, perform standard measurements for patient diagnosis and assessment, and compare the anatomy or objects to archetype models. Any number of multimodal bioimages can be added to the calibrated environment following a calibration and coregistration process. Assigning a common Cartesian coordinate system centered within the patient’s anatomy can optimize the visualization and analytical processes within the calibrated environment. Simultaneous visualization and analysis of multiple images correlated to the common coordinate system of an anatomic model create the opportunity to extract the best features of the combined image set to aid in landmark identification, defining and segmenting tissues, evaluating anatomic structures, building patient-specific models, and providing accurate anatomic data for research. Table 4-2 compares common bioimaging sources and rates their attribute contribution to provide accurate and useful craniofacial data to be used in measurements and diagnostics for patient assessment.

Accurate three-dimensional craniofacial morphometric data can aid the clinician in making informed decisions regarding the initial condition of the patient, aid in treatment decisions, assist in understanding the anatomic effects of time and/or treatment, and compare data to a reference data source to determine current status and predictions about growth and development. The same morphometric data would be valuable to researchers and developers of new technology and treatment processes. All transactions of sharing software, data, images, models, treatment results, and research results could be done over the Internet under Digital Imaging and Communications in Medicine (DICOM) and Health Insurance Portability and Accountability Act (HIPAA) compliance to protect patient information, with patient specific-identification data deleted or coded to ensure patient privacy.

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†References 34, 46, 52–58.

TABLE 4-2 Ranked Attributes of Common Image Sources*

	Two-Dimensional Sources				Three-Dimensional Sources					
Imaging Goal	**Cephalometric**	**Tomographic**	**Panoramic**	**Periapical**	**Fan Beam CT**	**Cone Beam CT**	**MRI**	**Laser**	**Structured Light**	**Three-Dimensional Patient Model**
Face: soft tissues	*	—	—	—	**	**	**	***	****	****
Tooth crowns	*	—	*	*	**	**	*	****	***	****
Tooth roots	—	**	**	**	***	***	**	—	—	***
Identify internal anatomy	*	***	**	**	****	****	****	—	—	****
Localize anatomy	*	***	*	*	****	****	***	—	—	****
Determine jaw boundaries	—	***	**	—	****	****	***	—	—	****
TMJ (bones)	—	***	*	—	****	****	***	—	—	****
TMJ disk	—	—	—	—	—	—	****	—	—	****
Airway	**	**	—	—	****	****	****	—	—	****
Face surface geometry	**	*	**	*	***	***	***	****	****	****
Color rendering of face	—	—	—	—	—	—	—	***	****	****

*A list of commonly used imaging techniques and associated imaging goal. The relative application value for each imaging technique has been rated as follows: —, no value; *, low value; **, moderate value; ***, high value; ****, highest value.

CT, Computed tomography; *MRI,* magnetic resonance imaging; *TMJ,* temporomandibular joint.

Patient-Specific Anatomic Reconstructions

The overall goal of imaging is to accurately record and display the anatomic structure(s) of interest. This process involves the selection of the appropriate imaging modality to obtain this information, and often additional and complementary imaging modalities are used to obtain all the necessary information. The integration of various imaging data to construct a PSAR has enormous potential. A complete PSAR with the craniofacial skeleton, teeth, soft tissues including muscles, and their parameters of movement and force generation could be immensely useful. With this information, patient-specific models could be used not only for diagnosis but also for further applications such as treatment simulation and testing of hypotheses. A perturbation or treatment could be introduced in a local anatomic region—for example, a dental occlusal interference or removal thereof—to determine the effect on a regional environment such as the jaws and the TMJs. Another example applicable to patient-specific models is biomechanical analysis and evaluation of stresses in the local and regional environments. Additionally, the effect of biomechanical influences on growth and development could be studied. This has widespread implications for tissue engineering and craniofacial reconstructions. To achieve such patient-specific models, imaging sources with varying geometric structure and data format need to be registered and integrated. Imaging modalities to obtain three-dimensional data of tooth crowns and tooth roots are described next. Technologies to obtain three-dimensional facial images and the craniofacial skeleton were described previously.

Dynamic Model

A comprehensive model of the orthodontic patient would not be complete without information on mandibular position and its dynamics during function. The dental articulator is used commonly to record mandibular positions; however, these are essentially terminal jaw positions determined by the use of bite registrations. The articulator does not record the exact paths of mandibular movement and its borders of motion. Recently, jaw-tracking devices have been developed to track the mandibular range of motion and its position relative to the maxilla and cranium, as well as velocity of opening and deviations of opening and closing in three dimensions. The two basic approaches are opticoelectric and ultrasonic-based methods. The opticoelectric technique uses an array of video cameras to record markers that are positioned on the patient.[52] The ultrasonic approach uses an array of microphones secured to the patient's head to record changes in ultrasonic frequency with different jaw positions (Figure 4-13).

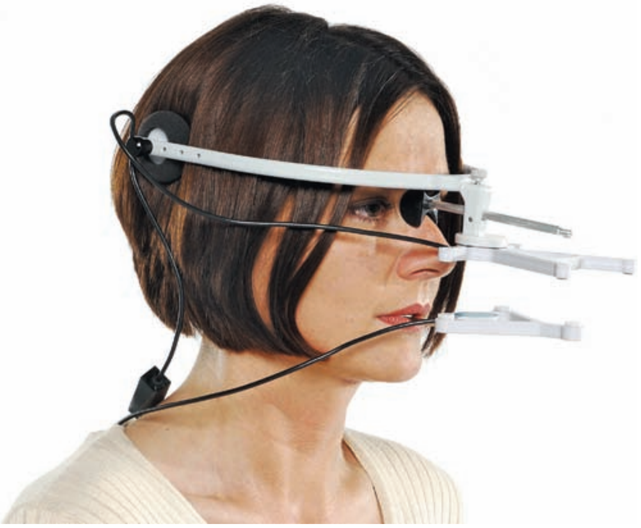

FIGURE 4-13 Functional dynamics of the jaw can be recorded by using an ultrasonic approach with an array of microphones secured to the patients. *(Image provided by Zebris Medical GmbH, Germany.)*

Another goal in the dynamics of mandibular movement is to establish the relative contributions of the various muscles of mastication. Electromyography of these muscles has been used for research purposes; however, the current state is such that this technology is not in common clinical use.

VISUALIZATION

The introduction of two- and three-dimensional digital imaging acquisition devices into orthodontics is beginning to change the viewing environment from a light box transillumination of radiographs to interactive viewing of data volumes using a computer workstation and monitor. Two-dimensional digital images are composed of subunits called picture elements (pixels), and three-dimensional digital images are composed of volume elements (voxels). The voxel and pixel attributes include dimensions, location, and value. The CBCT and newer generations of multirow detector CT scanners allow for the acquisition of isotropic voxels (x, y, and z axes are equal dimension) that range from less than 0.1 to 0.6 mm per axis. The x, y, and z locations of the voxels are stored in the computer workstation. The attenuation coefficient values of the tissues are converted to a grayscale format, such as 256 (8-bit), 4096 (12-bit) shades of gray, or 16,384 shades of gray (14 bit) in the latest devices. Each pixel or voxel is assigned a grayscale value that corresponds to the averaged density of all of the tissues contained within that volume. This averaged density is referred to as volume averaging. Volume averaging is a potential source of information loss, more so when the voxel dimension is large.

A tremendous amount of anatomic information is contained within the voxel volumes, and this information can be retrieved, analyzed, and viewed at a computer workstation using visualization and analytic software. The computer monitor is a two-dimensional 8-bit display used to display three-dimensional 12-bit image data. The 12-bit data can be viewed on an 8-bit display using a technique of windowing that allows for visualization of the entire 4096 shades of gray, 8 bits at a time. Often the anatomic volumes are acquired as voxel layers and stacked as a series of parallel cross sections of the anatomy. These stacks can be displayed and viewed as a series of two-dimensional cross sections by sequentially paging through them in orthogonal planes (sagittal, axial, and coronal); this is called multiplanar reformatting. Multiplanar reformatting is the two-dimensional display of three-dimensional data in multiple projection planes (Figure 4-14).

Spatial relationships between three simultaneous displayed planes are communicated by projecting one plane onto the corresponding orthogonal planes as lines. Because the anatomic structures of interest occupy multiple layers within a stack, the clinician needs to perform a mental reconstruction of the anatomy. Coronal, sagittal, and axial views can be linked with synthesized views, such as oblique and curved slices or slabs. Slices or slab thickness can be manipulated directly and in real time. The volume or slab of image data can be viewed with different modes of display, including maximum intensity projection, minimum intensity projection, shaded-surface rendering, and volume rendering.

Maximum intensity projection (MIP) can be used to highlight features. The anatomic features associated

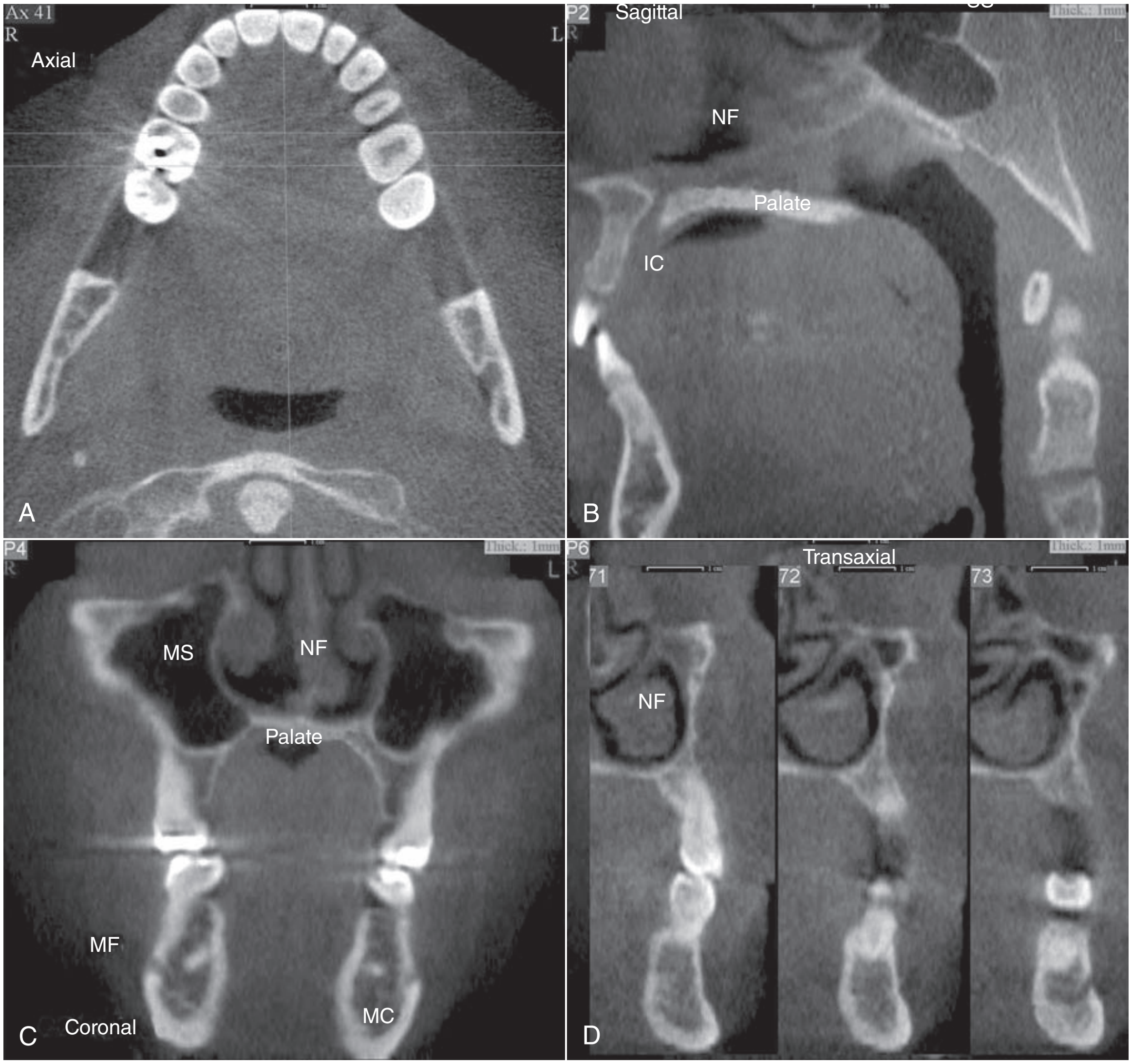

FIGURE 4-14 Visualization: multiplanar projections. This series of images was created from a NewTom cone beam computed tomography scan of the jaws. **A,** An axial view produced at the level of the mandibular dentition. **B,** A midsagittal plane reconstruction. **C,** A coronal section through the premolar region of jaws. **D,** A sequence of transaxial views of the left premolar region. Selected anatomy has been labeled as follows: *NF,* nasal fossa; *IC,* incisive canal; *SS*, sphenoid sinus; MS, maxillary sinus; *Palate,* hard palate; *MF,* mental foramen; *MC,* mandibular canal.

with the brightest pixel or voxel intensity are projected on the display screen. This method creates a high contrast image, but the brighter pixels/voxels may mask or superimpose over less bright pixels, thus potentially hiding important anatomic features. Maximum intensity projections of a CBCT volume or slab (right or left sides) may be a useful method to produce constructed cephalometric images for orthodontic purposes (Figure 4-15). *Minimum intensity projection* displays the pixel or voxel of the least value. This protocol would be useful for highlighting or display features associated with a low attenuation value, such as the airway. Shaded-surface rendering is useful for high-contrast imaging such as bone. Surface-shaded rendering techniques allow the operator to set a pixel or voxel intensity threshold that excludes structures lower than the selected threshold and renders all structures greater than the selected threshold (Figure 4-16). *Surface-shaded rendering* creates a three-dimensional model that can be rotated as an object to be viewed from any angle. When the tissue contrast is not high, then the selected threshold may not render the desired anatomy perfectly. *Volume rendering* also creates a three-dimensional model using no pixel/voxel threshold for data exclusion (Figure 4-17). The entire volume is always loaded, but tissues are grouped interactively by voxel intensity, and each group can be assigned a color and transparency value before projecting the volume onto the viewing monitor. The operator can rotate the volume-rendering model and change the opacity levels, thus providing the sense of peeling away tissues layer by layer. Volume rendering is a good way to understand the anatomic relationships between structures visually and can be used effectively for treatment planning and as a communication tool.

APPLICATIONS OF EMERGING TECHNOLOGY

Orthodontic Records

The greatest recent innovation has been the inclusion of the spatially true-size three-dimensional digital image data into the orthodontic records. Ultimately, the three-dimensional records will replace the two-dimensional records. The next-generation CBCT or volumetric CT promises to produce in a single scan enough information to eliminate the need for conventional panoramic, occlusal, cephalometric, selected periapical, and TMJ tomographic studies. The CBCT data will be superior to those gained from the compiled series of two-dimensional images and the absorbed dose will be less.

Temporomandibular Joint Evaluation

For individuals seeking orthodontic treatment to have TMJ conditions that may alter the size, form, quality, and spatial relationships of the osseous joint components is not uncommon. When these conditions occur during development, they may alter the growth of the ipsilateral half of the mandible with compensations in the maxilla, tooth position, occlusion, and cranial base. Severe TMJ conditions also may alter the facial growth pattern. Skeletal and dental changes occur in the vertical, horizontal, and transverse directions, thus making them difficult to characterize accurately with conventional two-dimensional imaging, such as cephalometric, tomographic, and panoramic projections (Figure 4-18). CBCT creates the opportunity to visualize and quantify the local and regional effects associated with the

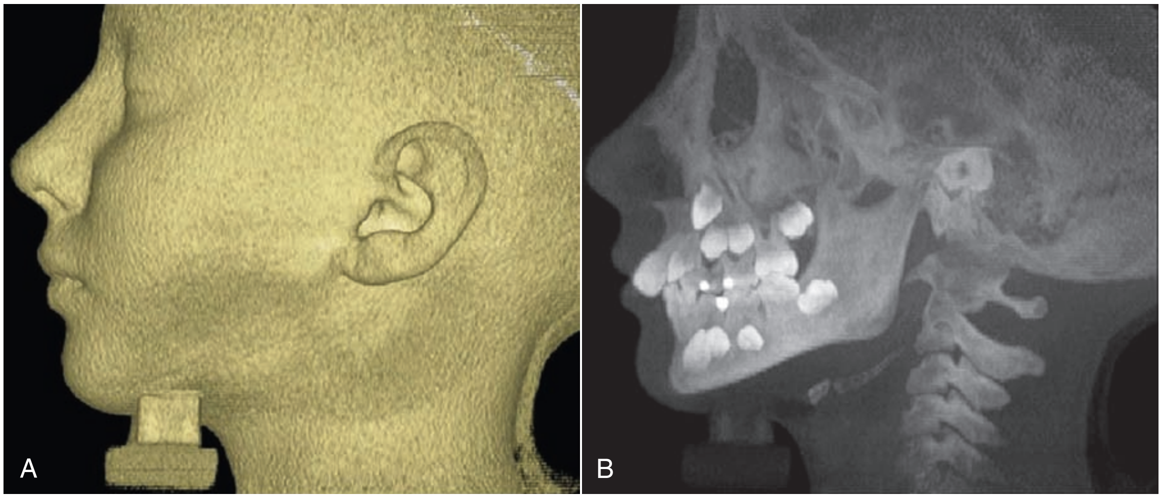

FIGURE 4-15 Visualization by NewTom upgrade showing a large field of view. **A,** Shaded-surface rendering of the soft tissue. **B,** Maximum intensity projection to create a cephalometric-like projection.

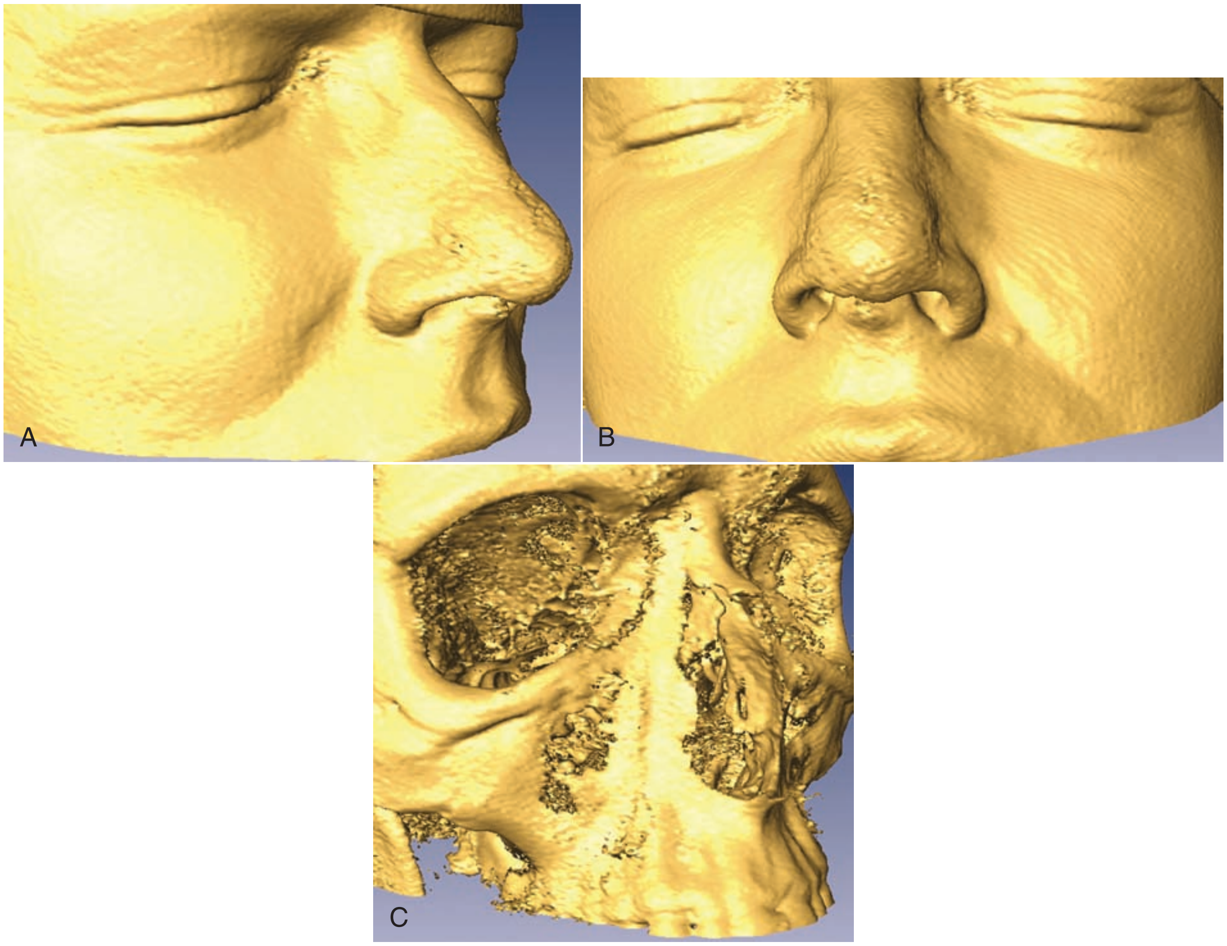

FIGURE 4-16 Visualization by shaded-surface rendering. A 12-bit cone beam computed tomography scan of the midface was produced using the I-CAT and rendered with Amira software. These are shaded surface displays with the thresholds set to allow visualization of the facial soft tissue **(A, B)** and bone surface **(C).**

TMJ abnormalities. CBCT allows, for the first time, visualization of the TMJs and at the same time assessment of the maxillomandibular spatial relationships and occlusion (Figure 4-19).

Orthodontic Boundary Conditions

The anatomy sets some of the boundary conditions for tooth position. Identification and visualization of these boundary conditions can be performed by applying volumetric CT during initial workup. In some clinical instances, tooth movement is prevented or diminished because of anatomic boundaries, such as cortical margins, adjacent teeth, and dense bone. In addition, expansion of the dental arch form or tooth torque may be limited or confined by the labial and buccal cortical margins of the alveolar bone (Figure 4-20). These boundaries are difficult to visualize without the aid of cross-sectional or three-dimensional imaging techniques (Figure 4-21).

Implants

Implants are used for anchorage to mobilize teeth or dental segments and in some cases can be restored to optimize function and aesthetics. Implants need to be located where they will have the best chance for success and for the aesthetic support of the lips and facial soft tissues, not only in a static state but also in normal function (e.g., smiling, talking). Prosthetic, anatomic, and biomechanical requirements independently or in combinations are key considerations to be resolved. Three-dimensional imaging techniques can play a significant role in revealing the anatomic considerations and linking them to the prosthetic and biomechanical treatment options (see Figure 4-7).

Impactions

Imaging can contribute greatly to localizing impacted teeth, identifying associated pathologic conditions,

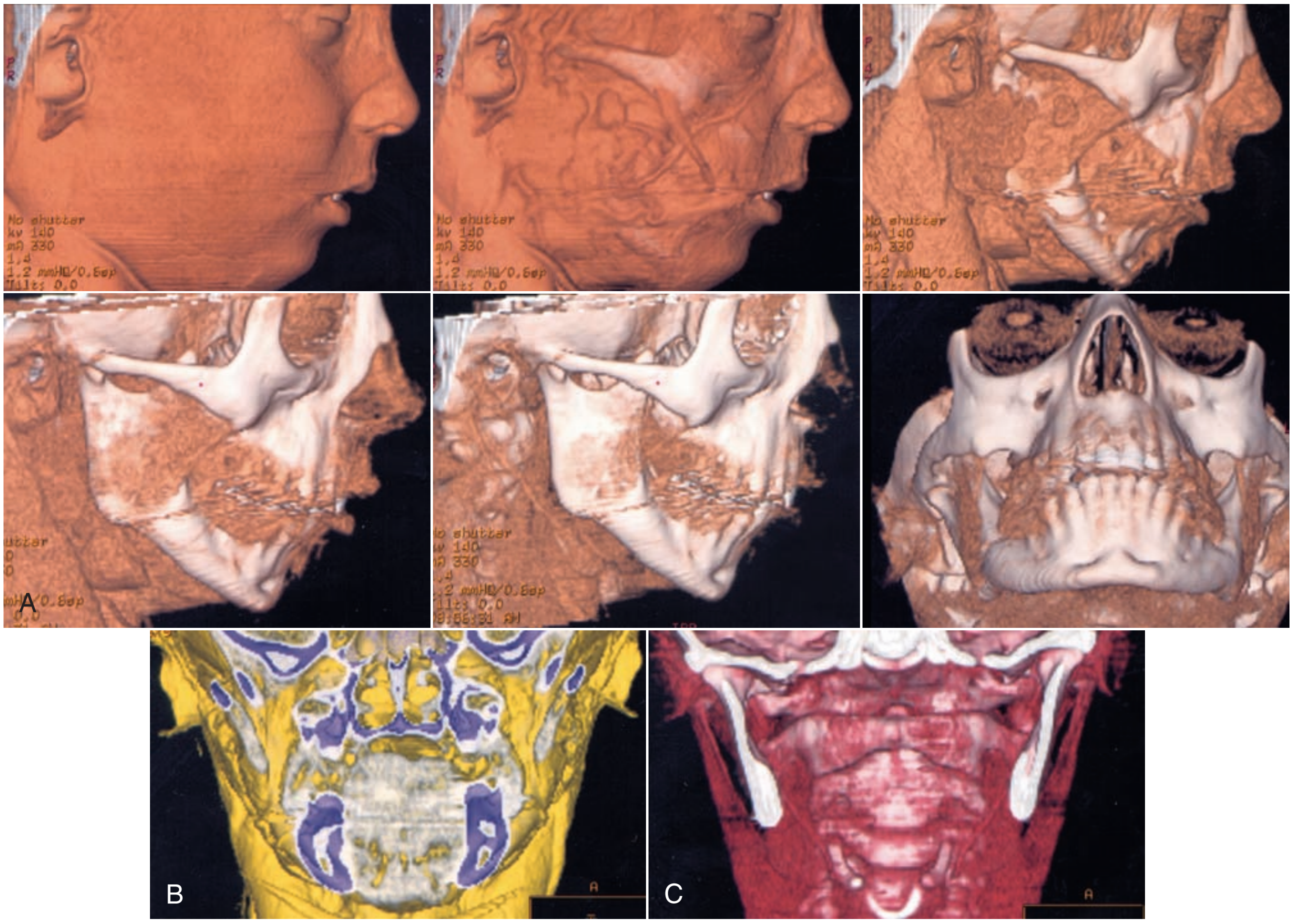

FIGURE 4-17 Clinical application of volume rendering. This is a series of volume-rendered images of computed tomography image data for a 4-year-old boy with a congenital inability to produce jaw motion. The volume rendering strategy was designed to show the bone–muscle relationships. **A,** Panel of images that produce the appearance of peeling away the tissue layers. The tissues with the lowest attenuation values get the highest transparency value. This exercise revealed bilaterally enlarged coronoid processes. When the transparency value for muscles was set at 100%, soft tissue fibers could be visualized extending from the coronoid tips to the base of the skull, and similar fibers were observed along the anterior surface of the superficial masseter muscle extend from the mandible (ramus) to the zygoma. **B,** Coronal view. To aid with visualization, the data for the anterior region of the face were removed to show the coronoid processes, and selected tissues were assigned colors as follows: cortical bone, *white*; medullary bone, *purple*; and the remainder of the soft tissues, *yellow*. The soft tissue fiber extending from the coronoid tip to the base of the skull rendered a *white* color similar to tendon. **C,** Coronal section at the level of the temporomandibular joints. The fibers extending from the coronoid processes and those along the anterior border of the superficial masseter muscles were severed, and this allowed the mandible to move.

assisting in planning surgical access, and assisting with designing the traction mechanics (i.e., the vector and direction of forces) for moving the impacted tooth into the dental arch and occlusion (Figure 4-22). Impacted canines, many times, are in close approximation to the lateral incisor roots or may have already affected the roots,[61] and the first movement may need to be *distally* away from the lateral roots BEFORE the canine is moved toward the arch.

Aesthetics

Volumetric CT captures the spatial relationships between the maxillofacial hard and soft tissues (Figure 4-23). Software can aid in visualization and quantification of the hard and soft tissue relationships. Anatomic models can be constructed from the CT volume and coregistered with other available three-dimensional image data. Databases can be linked to the anatomic models in a way that they provide the modeled tissues with attributes that will predict and simulate tissue responses to growth, treatment, and function. For example, facial soft tissues can be attributed with viscoelastic properties and linked to the underlying hard tissues so that simulated manipulation of the hard tissues (teeth and skeleton) produces an appropriate deformation response in the associated soft tissues. 3dMD (Atlanta, Georgia) is working with Dr. Steve Schendel, former chief of plastic and reconstructive

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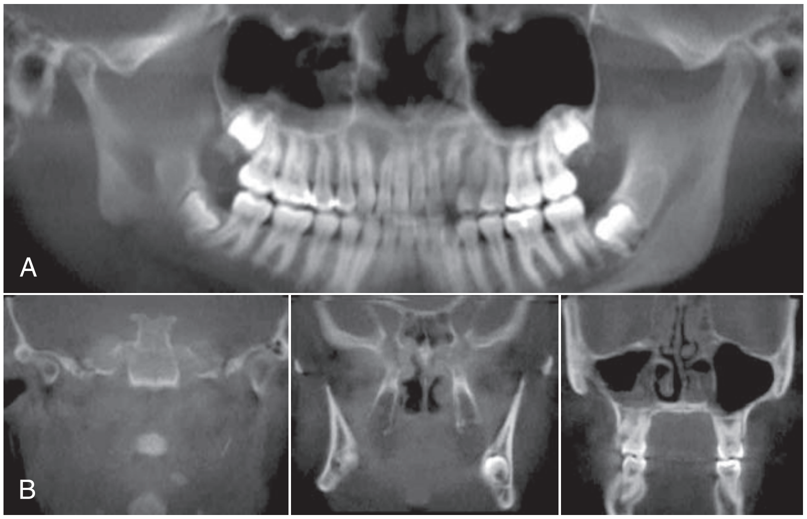

FIGURE 4-18 Asymmetry. Cone beam computed tomography of patient in Figure 4-2 using the NewTom 9000 volume scanner. **A,** A reconstructed panoramic projection showing the size and form of the condyles positioned with their fossa and at the same time showing the teeth in occlusion. The right half of the mandible has a smaller vertical dimension than the left half. **B,** A sequence of coronal images. The left coronal image was shown at the level of the temporomandibular joints. The right condyle was smaller than the left condyle. The right side cranial base was slightly lower than the left side. The middle coronal section was acquired at the level of the coronoid processes. This shows that the right side of the mandible was smaller than the left side and that the vertical orientation of right ramus was less vertical than the left side. The right side coronal image was produced at the level of the first molars, showing their intercuspation. The occlusal plane was elevated slightly on the right side, and the vertical orientation of the long axis of the right side body of the mandible was less than the contralateral side.

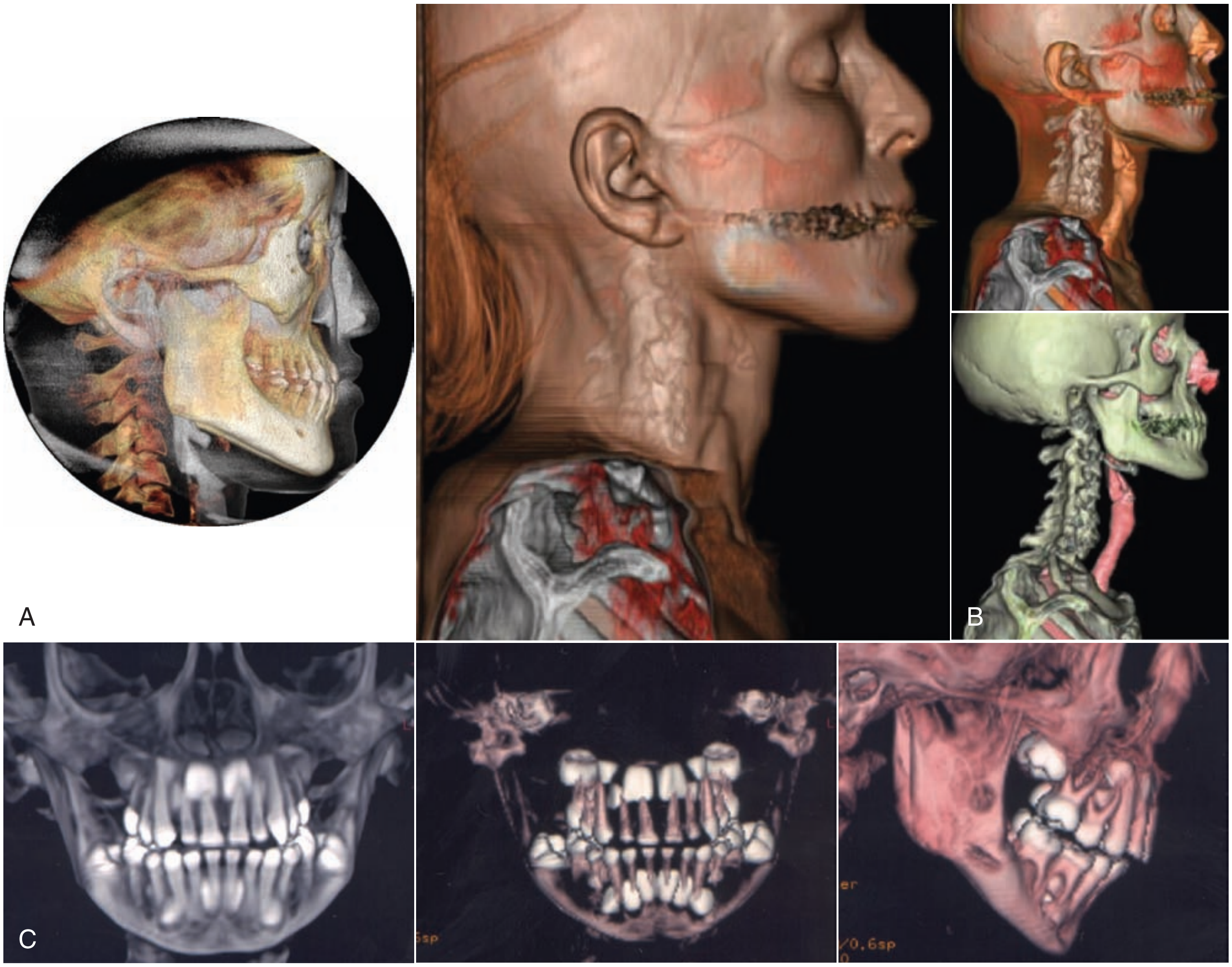

FIGURE 4-19 Visualization by a series of volume-rendered images acquired with cone and fan beam computed tomography. **A,** Hitachi cone beam computed tomography rendered with Cybermed V Works. **B,** Fan beam computed tomography rendered by TeraRecon software. **C,** Fan beam computed tomography rendered with General Electric software.

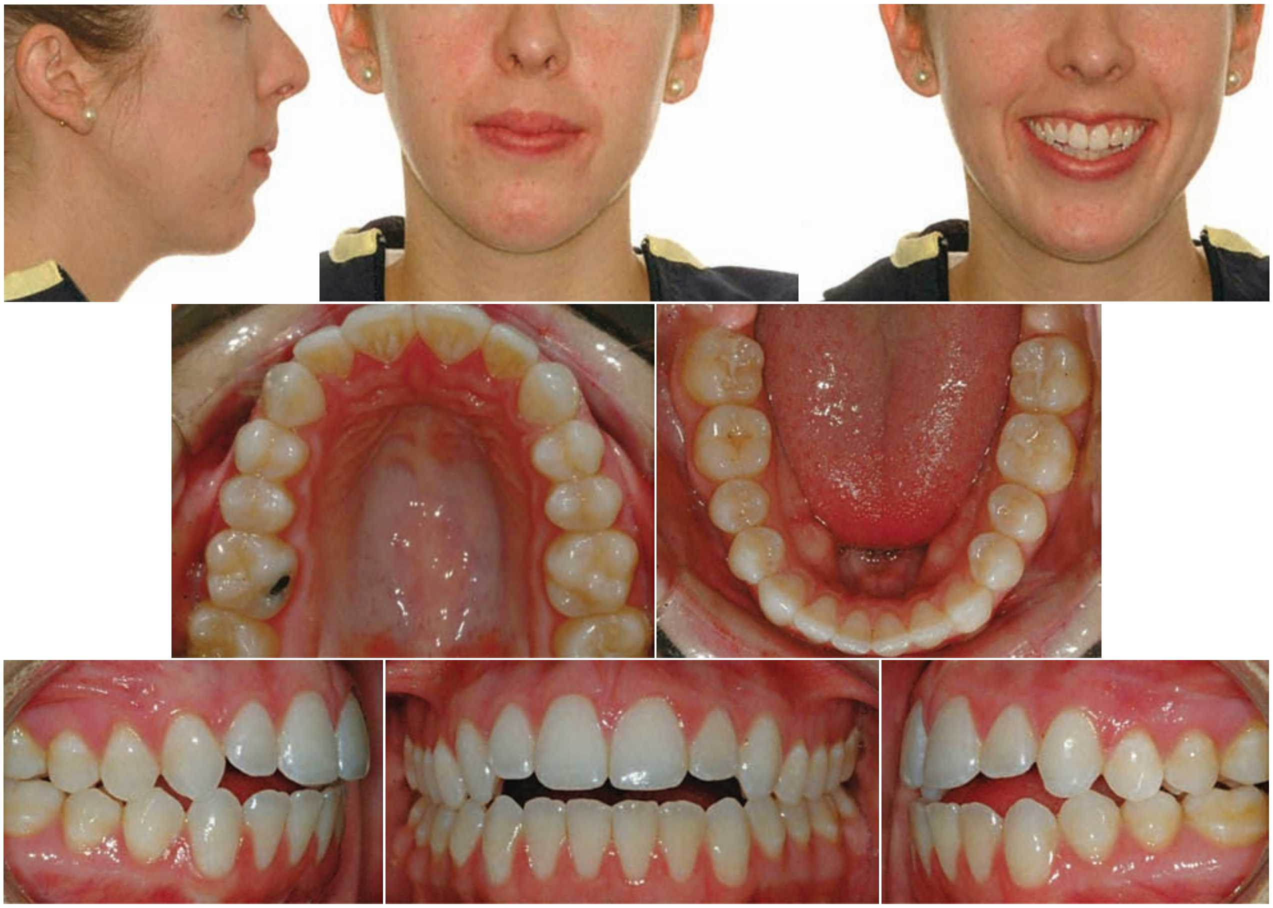

FIGURE 4-20 Boundary conditions. A 21-year-old female preorthodontic patient with an anterior open bite. The series of photographs shows a long anterior face height, anterior open bite, and arch form.

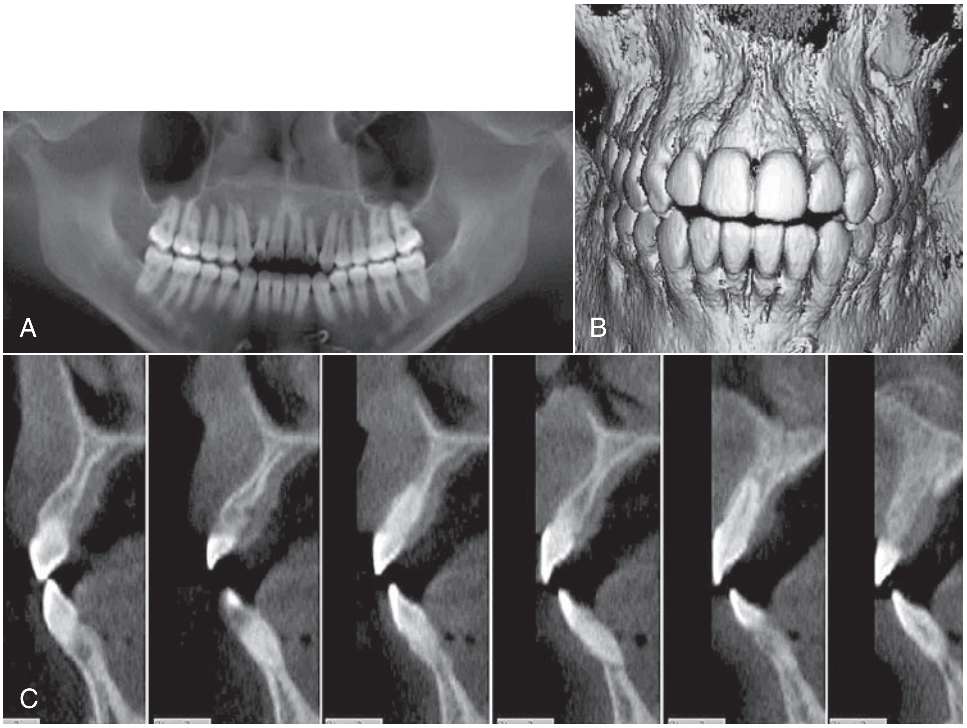

FIGURE 4-21 Reconstructions of a NewTom 9000 cone beam computed tomography for patient in Figure 4-19. **A,** A panoramic reconstruction showing small condyles, short rami, obtuse gonial angles, and anterior open bite. **B,** Shaded surface display showing anterior teeth and supporting bone. **C,** Transaxial reconstructions of selected anterior teeth showing the anterior open bite, the axial inclination of the teeth, and supporting bone. Note the narrow labiolingual thickness of bone, particularly apical to the roots of the teeth.

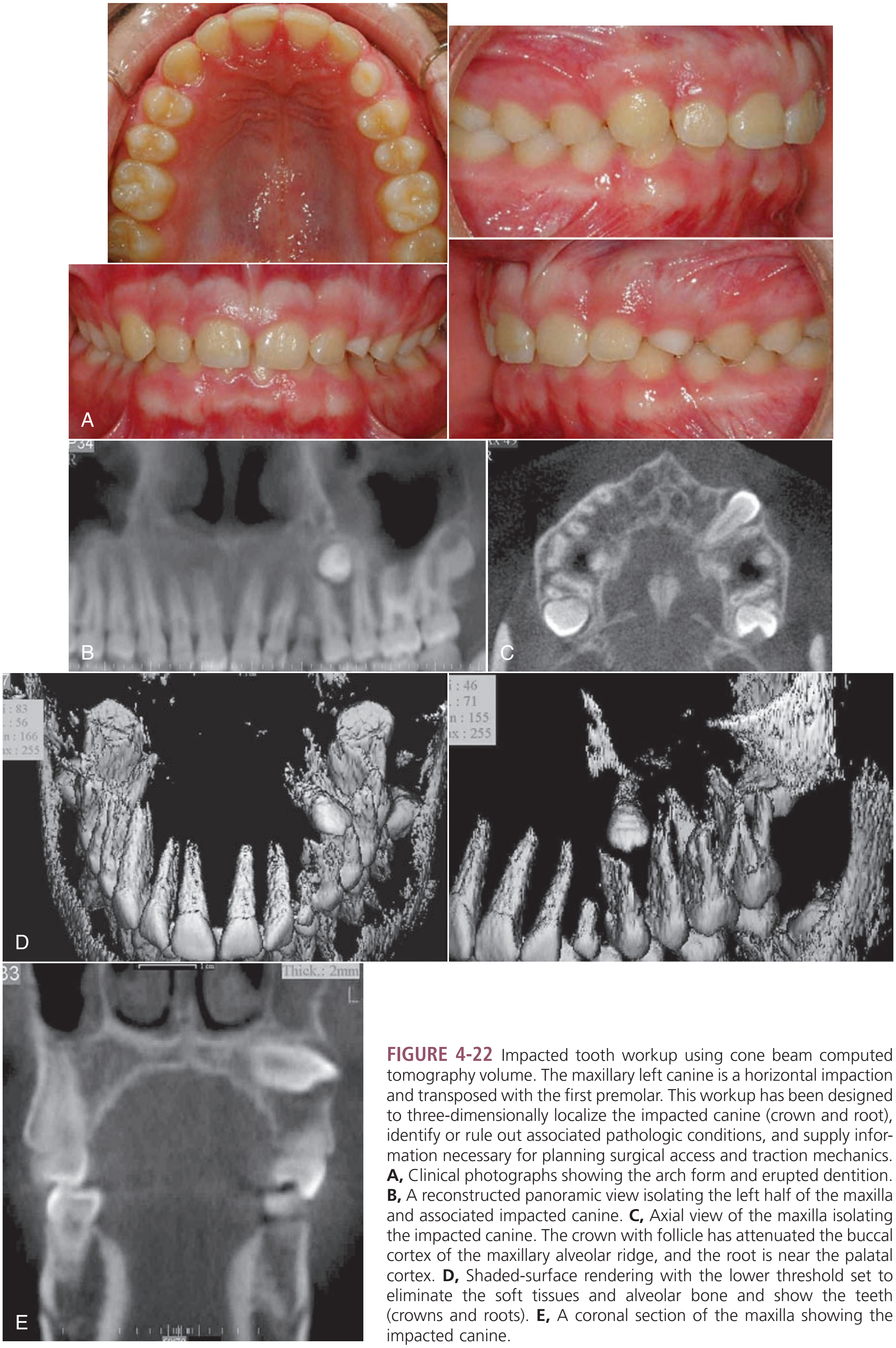

FIGURE 4-22 Impacted tooth workup using cone beam computed tomography volume. The maxillary left canine is a horizontal impaction and transposed with the first premolar. This workup has been designed to three-dimensionally localize the impacted canine (crown and root), identify or rule out associated pathologic conditions, and supply information necessary for planning surgical access and traction mechanics. **A,** Clinical photographs showing the arch form and erupted dentition. **B,** A reconstructed panoramic view isolating the left half of the maxilla and associated impacted canine. **C,** Axial view of the maxilla isolating the impacted canine. The crown with follicle has attenuated the buccal cortex of the maxillary alveolar ridge, and the root is near the palatal cortex. **D,** Shaded-surface rendering with the lower threshold set to eliminate the soft tissues and alveolar bone and show the teeth (crowns and roots). **E,** A coronal section of the maxilla showing the impacted canine.

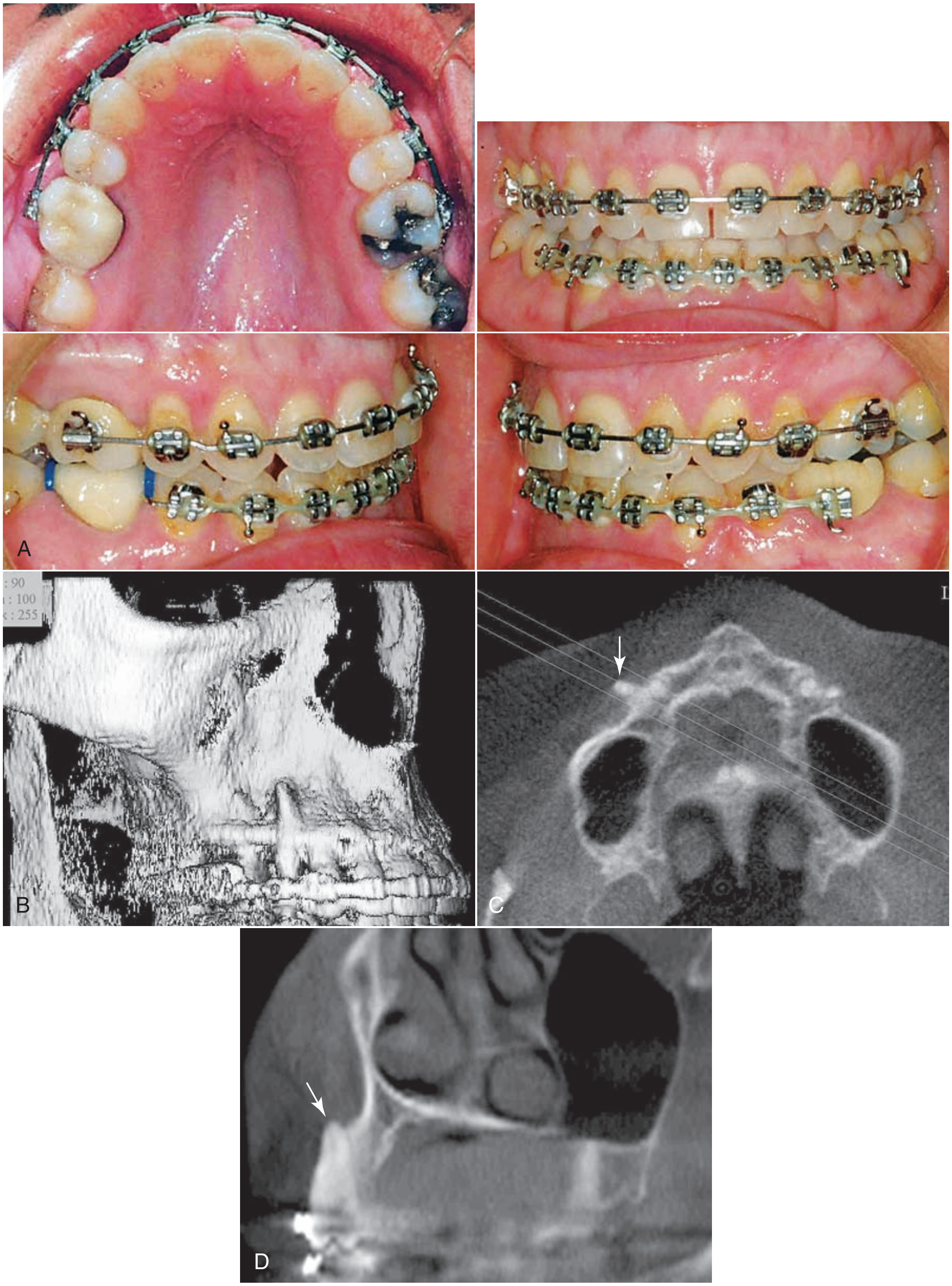

FIGURE 4-23 Boundary conditions. Three-dimensional volume scans can be used to assess the jaw dimensions and tooth position. **A,** Clinical photographs of a 46-year-old woman with complaint of painful lump in buccal vestibule maxillary right premolar region. **B,** Shaded-surface rendering showing the root of right maxillary premolar tooth positioned buccal to the alveolar bone. **C,** Axial view of the maxilla. The root tip is located lateral to the alveolar process (*arrow*). **D,** Transaxial view of the maxilla showing the entire length of the premolar tooth and the location of the root tip outside of the dental arch (*arrow*).

surgery at Stanford University, on "mass springs" models to physiologically attribute the facial soft tissues to the underlying hard tissues and simulate changes in soft tissue from dental and skeletal movements or vice versa.[42,43]

Orthognathic Surgery and Distraction Osteogenesis

The craniofacial hard and soft tissues and their spatial relationships can be analyzed on patient-specific models using appropriate software. The analyzed model then can be used to simulate or test treatment options and ultimately will be used to assist at time of treatment (see Figure 4-4, *D*).

SUMMARY

Orthodontic imaging has come a long way since the "plaster era" during the times of Edward Angle and Calvin Case, when plaster was the recording medium for the dentition as well as facial form. Although the use of plaster provided three-dimensional information, there were limitations.

With the advent of dental impression materials and radiographic and photographic film, the orthodontic patient record evolved into the "film era." Developments in photography and radiography since then have evolved into the technologies used in current orthodontic practice. Despite their limitations, these methods have served orthodontists well as research tools, diagnostic aids, and medicolegal records.

We are now into the "digital era," in which new digital imaging technologies are being used to resolve previous limitations of the patient record. This technology offers three-dimensional capabilities that allow vastly improved insight and understanding of patients. For example, in the localization of maxillary impacted canines, the use of a panoramic image alone fails to reliably differentiate its position from the palatal or buccal.[42] The combination of panoramic and occlusal films results in an improvement of diagnostic sensitivity to 69% to 88%.[43] By using three-dimensional CBCT to localize impacted canines, the determination is true and free of the previous projection and superimposition limitations.

Imaging has evolved from merely a diagnostic aid to advanced functions such as patient-specific modeling (PSAR) and virtual treatment simulations. Three-dimensional information has allowed for computer-assisted design approaches to orthodontics, enabling the manufacturing of items such as surgical models, guides, and other patient-specific appliances. Upcoming developments allow for hypothesis testing and biomechanical analysis of the three-dimensional patient data. In this manner, orthodontic materials can be selected and tested on the virtual patient before appliance fabrication and patient treatment. Continuing evolution in orthodontic imaging and treatment of virtual patients is such that these techniques will be key to future orthodontic practice.

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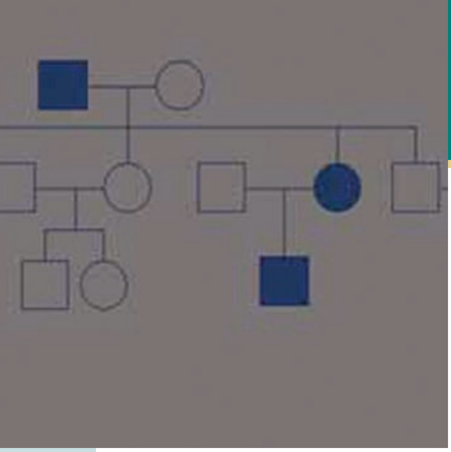

CHAPTER 5

Genetics and Orthodontics

James K. Hartsfield, Jr.

OUTLINE

- **Cause**
- **Basic Definitions**
- **Types of Genetic Effects and Modes of Inheritance**
    - Monogenic Traits
        - *Autosomal Dominant Traits and Penetrance*
        - *Variable Expressivity*
        - *Autosomal Recessive Traits*
        - *X-Linked Traits and Lyonization*
        - *Human Monogenic (Mendelian) Traits Online Database*
        - *Mandibular Prognathism*
    - Complex (Polygenic/ Multifactorial) Traits
- **Nature versus Nurture**
    - Heritability and Its Estimation
    - Craniofacial Skeletal and Dentoalveolar Occlusal Heritability Studies
    - Use of Family Data to Predict Growth
- **Tooth Size, Hypodontia, and Dental Root Development**
- **Environmental and Genetic Influences on Bilateral Symmetry**
- **Investigating the Genetic Basis for Variable Response to Treatment**
- **Genetic Factors and External Apical Root Resorption**
- **Pain Perception and Temporomandibular Dysfunction**
- **Human Genome Project and Beyond**
- **Summary**

Malocclusion is a manifestation of genetic and environmental interaction on the development of the orofacial region. Orthodontists may be interested in genetics to help understand why a patient has a particular occlusion. Consideration of genetic factors is an essential element of diagnosis that underlies virtually all dentofacial anomalies. This part of the diagnostic process is important to understanding the cause of the problem before attempting treatment. Knowing whether the cause of the problem is genetic has been cited as a factor in eventual outcome; that is, if the problem is genetic, then orthodontists may be limited in what they can do (or change).[1–3] In the orthodontic literature, there are inappropriate uses of heritability estimates as a proxy for evaluating whether a malocclusion or some anatomic morphology is "genetic." As will be explained, this had no relevance to the question. How genetic factors will influence the response to environmental factors, including treatment and the long-term stability of its outcome as determined by genetic linkage or association studies, should be the greatest concern for the clinician.[4,5]

CAUSE

Consideration of the cause of a malocclusion requires careful consideration of the following:

1. Most problems in orthodontics (or any outcome of growth), unless acquired by trauma, are not strictly the result of only genetic or only environmental factors.[6]
2. Growth is the result of the interaction of genetic and environmental factors over time.[7,8]
3. Most of the studies regarding the genetics of craniofacial growth are analyses of heritability that estimate the proportion of the total phenotypic variation of a quantitative trait that can be attributed to genetic differences between individuals but that do not determine the type of genetic influences—that is, monogenic versus complex.[5]
4. Even if the growth outcome is influenced heavily by multiple genetic (polygenic) factors, that does not mean that the growth from that point on

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is necessarily or absolutely predetermined or on a particular immutable track, although it may be predisposed to remain on the same track if the influence is monogenic.

5. The response to a particular environmental factor (e.g., treatment) does not necessarily depend on the prior interaction of genetic and environmental factors, but rather on the response of the individual to the new environmental factor (e.g., treatment). The outcome of treatment will be a function of the interaction of proteins from genetic factors that are expressed (or not) and the other environmental factors present at that time, against the backdrop of the developmental maturity of the individual.[9–12] It is important to understand the cause of the problem. Much of the literature in orthodontics about genetics has discussed the contribution of genetic factors to growth and malocclusion. The most important practical question regarding orthodontics and genetics is whether different individuals respond to some degree to a changed environment (treatment) in different ways according to the influence of their particular genetic factors.

BASIC DEFINITIONS

Before proceeding, a few basic definitions are required. The genome contains the entire genetic content of a set of chromosomes present within a cell or an organism. Genes represent the smallest physical and functional units of inheritance that reside in specific sites (called *loci* for plural or a *locus* for a single location) in the genome. A *gene* can be defined as the entire DNA sequence necessary for the synthesis of a functional polypeptide (production of a protein via a messenger or mRNA intermediate) or RNA (transfer, or tRNA, and ribosomal, or rRNA) molecule.[13] *Genotype* generally refers to the set of genes that an individual carries and, in particular, usually refers to the particular pair of alleles (alternative forms of a particular gene) that a person has at a given region of the genome. In contrast, *phenotypes* are observable properties, measurable features, and physical characteristics of an individual,[14] as determined by the individual's genotype and the environment in which the individual develops over a period of time. For further information, the reader is referred to the reviews by Mossey,[2,15] Abass and Hartsfield,[16] and Lidral et al.[17]

TYPES OF GENETIC EFFECTS AND MODES OF INHERITANCE

A *trait* is a particular aspect or characteristic of the phenotype. When considering genetic influences on traits, it is convenient to think of three types: monogenic, polygenic, and multifactorial. Although defining these types can be helpful in understanding genetic influences, they are, to some degree, simplistic categorizations. If taken literally, the assigned classification would lead the reader to make presumptions about the interaction of genetic and environmental (nongenetic) factors, as well as the number of factors involved to a certain extent, and the extent to which the factors are involved in individuals.

Monogenic Traits

Traits that develop because of the influence of a single gene locus are *monogenic*. These types of traits also tend to be described as discrete or qualitative (dichotomous or yes/no) in occurrence. However, if they are present, these traits still may be variable and quantifiable in some cases. All human beings normally have 22 homologous pairs of chromosomes called autosomes that are numbered by size and other characteristics. In addition, one pair of sex chromosomes may be homologous (X, X) in females or only partly homologous (X, Y) in males. Genes at the same locus on a pair of homologous chromosomes are alleles. When both members of a pair of alleles are identical, the individual is homozygous for that locus. When the two alleles at a specific locus are different, the individual is heterozygous for that locus.

Autosomal Dominant Traits and Penetrance. If having only one particular allele of the two alleles on a homologous pair of autosomes (heterozygosity) is sufficient to lead to the production of the trait, the effect is autosomal dominant. If production of the trait does not occur with only one particular allele of the two alleles on an autosome but does occur when both alleles are the same (homozygosity), then the effect is autosomal recessive. Although the trait (phenotype) actually is dominant or recessive and not the gene itself, the terms *dominant gene* and *recessive gene* are used commonly to describe these types of inherited traits in families. The nature of these traits is studied by constructing family trees called *pedigrees* in which males are denoted by squares and females by circles, noting who in the family has the trait and who does not.

If the mode of inheritance for a particular trait is homogeneous, then the study of multiple families will yield the following criteria for autosomal dominant inheritance: (1) the trait occurs in successive generations; that is, it shows vertical inheritance (Figure 5-1); (2) on the average, 50% of the offspring of each parent who has the trait also will have the trait; (3) if an individual has the gene that results in the trait, each child has a 50% chance of inheriting the gene that leads to the expression of the trait; (4) males and females are equally likely to have the trait; and (5) parents who do not have the trait have offspring who do not have the trait.

Exceptions to this include the trait showing nonpenetrance in a particular offspring. When a person with a given genotype fails to demonstrate the trait characteristic for the genotype, the trait is said to show nonpenetrance in that individual and incomplete penetrance in

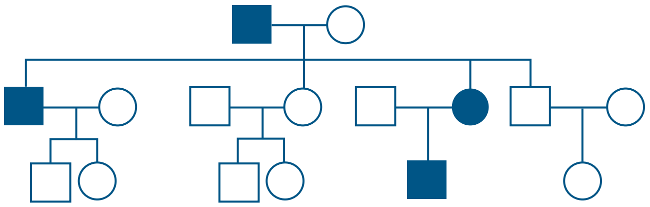

FIGURE 5-1 Three-generation pedigree of a family with an autosomal dominant trait with the younger generations below the older generations. Square symbols are male and round symbols are female. Affected members are denoted by filling in their individual symbol.

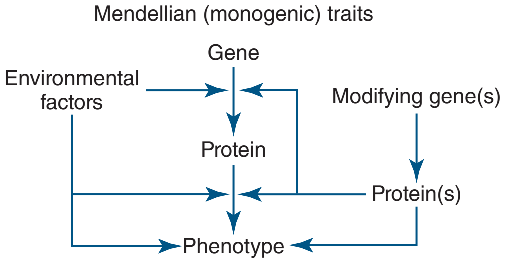

FIGURE 5-2 Mendelian (monogenic) traits or diseases result because a single gene polymorphism or mutation usually results in a recognizable phenotype. Environmental factors and other genes may modify the clinical expression of the disease or other type of trait but are not of crucial importance for its development.[16]

any group of individuals who have the genotype. The trait is present or not (nonpenetrant) in an individual. If some of the individuals do not manifest the trait in a sample of individuals with the trait-associated genotype, then the trait is said to have a penetrance of whatever percentage of the trait-associated genotype that the group actually manifests. This is a situation most commonly seen with dominant traits. Other exceptions are (1) a new mutation occurred in the sperm or egg that formed the offspring and (2) germinal mosaicism occurred, in which case one of the parents is mosaic in the germ cell line and the sperm or eggs are of two types—one cell line with and one cell line without the mutation. Chance determines which sperm cell line will be passed on. The other obvious exception is nonpaternity. Although this is not strictly a genetic problem, the illegitimacy rate in the U.S. population is high enough to make this a possible explanation for a couple without the trait to have a child with a completely penetrant dominant trait.

Variable Expressivity. Although in each individual the trait is present or not when discussing penetrance, if the trait is present, it may vary in its severity or expression. Thus, not all individuals with the trait may have it to the same extent and they may express varying degrees of effect or severity. Variable expressivity also may apply to the pleiotropic effect of a particular genotype; that is, the expression of the same gene may result in seemingly disparate traits in an individual. The association of two or more traits together more often than what would be expected by chance defines a *syndrome*. Although the term *genetic syndrome* often is used, not all syndromes necessarily have a strong genetic basis.

For example, at least four clinical types of osteogenesis imperfecta involving type I collagen abnormalities provide an illustration of variable gene expression: (1) multiple fractures, (2) blue sclera, (3) dentinogenesis imperfecta, and (4) hearing loss. Variation occurs among the different clinical types of osteogenesis imperfecta: Affected persons in a single family may show a variable combination and severity of the classic signs and symptoms, illustrating the considerable variation in gene expression even within a family, with presumably the same genetic abnormality in one of the genes that code for type I collagen. The minimum phenotypic expression of the gene observed in a family then might be only a blue color to the sclera, which could go unnoticed by the clinician. In this case, highly variable gene expression may fade into nonpenetrance.[18]

The craniosynostosis syndromes, along with their effect on craniofacial growth and development associated with premature closure of one or more cranial sutures, often result in maxillary hypoplasia and a Class III malocclusion. Most of these are autosomal dominant traits associated with single gene mutations that provide a good example of how, even with the strong influence of a single gene, the phenotype can vary considerably. Although at one time it was presumed that a particular mutation in a particular gene would always result in a specific syndrome, several identical mutations in the fibroblast growth factor receptor 2 (*FGFR2*) gene have been found in patients diagnosed with the three overlapping yet different clinical entities of Crouzon, Pfeiffer, and Jackson-Weiss syndromes.[19,20]

Further evidence for the variable expressivity in autosomal dominant phenotypes associated with a single gene mutation presumably resulted from the interaction of different proteins from modifying genes and environmental factors (Figure 5-2) occurring when individuals with, for example, the classic phenotypes of two overlapping but clinically distinct syndromes (Pfeiffer and Apert), as well as seven other individuals with a facial resemblance to yet another syndrome (Crouzon), occurred in the same family.[21]

Even with an autosomal dominant condition that typically manifests, the phenotype may be so variable that, as a second example, an individual may appear to be clinically normal yet have the same gene mutation associated with Crouzon syndrome as his three children and two of his grandchildren. In this case, only through cephalometry was a minimal expression of features suggestive of Crouzon syndrome evident.[22] These examples give a clear message: Even a generally extreme phenotype associated with an autosomal dominant mutation is variable. Simply discovering the gene mutation likely will indicate a future effect on craniofacial growth and development but will not necessarily predict the precise effect.

Autosomal Recessive Traits. The concept of a gene carrier is used with autosomal recessive traits. The carrier is heterozygous for a recessive gene that has only subtle, if any, expression of that single gene. Parents of a child with the autosomal recessive trait are typically heterozygous (carriers) and most often are diagnosed as normal. Sometimes, however, the carrier status can be detected, greatly improving the precision of genetic counseling, before a child being born with the recessive trait. In autosomal recessive traits, the following three gene pairs are found: AA—homozygous, not showing the trait or being a carrier for the trait; Aa—heterozygous, not showing the trait but being a carrier of the trait; and aa—homozygous, showing the trait.

The rarer the recessive gene, the more likely it is that normal parents who have an affected child will be blood relatives—that is, a consanguineous mating. Still, we all likely carry a number of recessive genes, so it is possible for unrelated couples to have a child with an autosomal recessive trait. A study on inbreeding in Japan by Schull and Neel that was cited by Niswander[23] found that malocclusion occurred 6% to 23% more often (depending on the sample and the sex) in children of first cousins compared with children of nonrelated parents, indicating the potential for the effect of recessive genes when homozygous.

Given that both parents who produce a child with an autosomal recessive trait are presumed to be heterozygotes, only one of the four possible gene combinations from the parents will result in the homozygous genotype associated with the autosomal recessive trait. Hence, the recurrence risk for an affected child in this case is 25%. Note that transmission of the phenotype in a pedigree is horizontal (typically present only in siblings) and not vertical, as with a dominant trait (Figure 5-3).

X-Linked Traits and Lyonization. Most of the genes on the X and Y chromosomes are not homologous and are unequally distributed to males and females. This inequality is because males have one X and one Y chromosome, females have two X chromosomes, and the genes active on the Y chromosome are concerned primarily with the development of the male reproductive system. For these reasons, males are hemizygous for X-linked genes, meaning that they have only half (or one each) of the X-linked genes. Because females have two X chromosomes, they may be homozygous or heterozygous for X-linked genes, just as with autosomal genes.

Interesting genetic combinations are made possible by the male hemizygous condition, which is the result of the male normally having only one X chromosome. Although the Y chromosome has some loci that correspond to loci on the X chromosome, most of the loci on the one X chromosome in the male do not have homologous loci on the Y or any other chromosome. Because a normally functioning homologous allele is not present on another chromosome, recessive genes on the one male X chromosome express themselves phenotypically as if they were dominant genes. However, X-linked recessive genes must be present at the same (homologous) locus in females to express themselves fully. Consequently, full expression of rare X-linked recessive phenotypes is almost completely restricted to males, although occasionally it is seen in females (Figure 5-4). However, females who are heterozygous for the gene associated with the X-linked recessive phenotype may show some expression of the phenotype because most of the genes on one of the X chromosomes in the female normally will be inactivated by a process called *lyonization.*

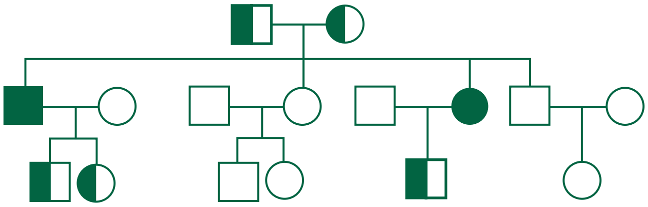

FIGURE 5-3 Three-generation pedigree of a family with an autosomal recessive trait. The symbols for presumed carriers (heterozygotes) of the autosomal recessive gene are filled in halfway. Some other family members also may be carriers but cannot be determined strictly from the pedigree.

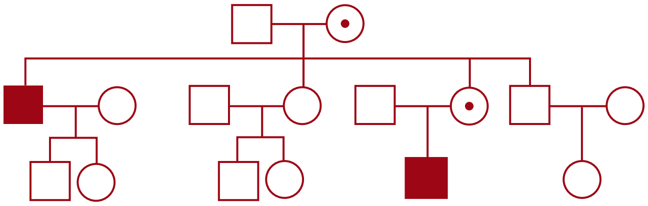

FIGURE 5-4 Three-generation pedigree of a family with an X-linked recessive trait. The symbols for presumed female carriers (heterozygotes) of the X-linked recessive gene have a dot in the middle of the circle. Some other female family members also may be carriers but cannot be determined strictly from the pedigree.

The lyonization process starts early in development when each cell in the female inactivates almost all of the genes on one of her two X chromosomes. The homologous X chromosome in each succeeding cell also will inactivate the same X chromosomes of the pair. Each female carrying a gene associated with an X-linked recessive phenotype has a variable number of cells in which the X chromosome, where the X-linked recessive associated phenotype gene is located, is inactivated. Under these circumstances, the inactivated chromosome does not influence the phenotype. The remaining cells having the X chromosome, where the X-linked recessive associated phenotype gene is on the "active" X chromosome, influence the phenotype.

Human Monogenic (Mendelian) Traits Online Database. The traits in peas that Mendel described in his inheritance studies happened to be monogenic; thus, monogenic traits sometimes are called mendelian traits.

A numbered database/catalog of human genes and genetic disorders associated with mendelian inheritance is available. Online Mendelian Inheritance in Man (OMIM), McKusick-Nathans Institute for Genetic Medicine, Johns Hopkins University [Baltimore, MD] and National Center for Biotechnology Information, National Library of Medicine [Bethesda]) may be searched at www.ncbi.nlm.nih.gov/sites/entrez?db=omim.

Mandibular Prognathism. Searching on the term *malocclusion* in OMIM reveals more than 40 entries for a variety of syndromes known to include malocclusion as one of their features. Although these are not all the monogenic syndromes or traits that may include malocclusion as a feature, the best-known example of familial "mandibular prognathism" is referred to as the Hapsburg jaw. The reference is OMIM *176700; the asterisk indicates that in the opinion of the database/catalog authors, mendelian inheritance is certain.

Although mandibular prognathism has been said to be a polygenic[24] or multifactorial trait (i.e, influenced by the interaction of many genes with environmental factors), in the majority of cases, there are families in which the trait (and possibly some other associated findings) appears to have autosomal dominant inheritance, such as in the European noble families. Analysis of a pedigree comprising 13 European noble families with 409 members in 23 generations determined that the mandibular prognathism trait was inherited in an autosomal dominant manner, with a penetrance of 0.95 (i.e, 95% of the time that someone was believed to have the gene for the mandibular prognathism trait in their pedigree, the trait itself also was expressed). Although the penetrance is high, considerable variation exists in the clinical expression of the trait.[25]

Also noted was that some of the members of the European noble families had, in addition to varying degrees of mandibular prognathism, other facial characteristics such as a thickened lower lip, prominent nose, flat malar areas, and mildly everted lower eyelids (which may be associated with a hypoplasia of the infraorbital rims), as also were reported in three generations of a family by Thompson and Winter.[26] In that family, one member had oxycephaly because of multiple suture synostosis, which also was suspected in Charles V, a severely affected member of the Hapsburg family. Apparent maxillary hypoplasia, as well as malar flattening and downward eversion of the lower eyelids, may indicate that although the trait is referred to as mandibular prognathism, the overall clinical effect may be at least in part due to hypoplasia of the maxilla. Even in the most recognizable family trait, there may be those who would be expected to have the trait and do not. Furthermore, variability in the severity of the trait and associated findings suggest more than an isolated effect on sagittal mandibular/maxillary growth.

El-Gheriani et al.[27] performed segregation analysis on 37 Libyan families of patients who had a Class III malocclusion and also concluded that the overall inheritance pattern best fit an autosomal dominant model. Cruz et al.[28] had a similar outcome when the majority of their Brazilian pedigrees suggested autosomal dominant inheritance with incomplete penetrance. They concluded that there was a major gene and a multifactorial component that influenced the expression of mandibular prognathism.

The genetic factors likely are heterogeneous, with monogenic influences in some families and multifactorial influences in others.[23] This contributes to the variety of anatomic changes in the cranial base, maxilla, and mandible that may be associated with "mandibular prognathism" or a Class III malocclusion.[29,30] The prevalence of Class III malocclusion varies among races and can show different anatomic characteristics between races.[31] Considering this heterogeneity and possible epistasis (the interaction between or among gene products on their expression), it is not surprising that genetic linkage studies to date have indicated the possible location of genetic loci influencing this trait in several chromosomal locations.[32,33]

Complex (Polygenic/Multifactorial) Traits

The predominant role of genetics in the clinic has been the study of chromosomal and monogenic phenotypes that are associated clearly with specific changes (mutations) in the genome of the individual. However, new knowledge and techniques are allowing the study of phenotypes that "run in families" but do not adhere to patterns of mendelian inheritance. These are referred to as *complex* or *common* diseases, as well as phenotypes or traits, reflecting their complex etiological interaction between genes from more than one locus and environmental factors (Figure 5-5). Another consideration is their greater incidence compared with monogenic phenotypes. Understanding the concept of genetic heterogeneity is critical to understanding the genetic influences on common phenotypes. [34] For example, although orthodontists often first classify a malocclusion as Angle Class I, II, or III, orthodontists also know that a number of different subtypes of occlusion have varying genetic and environmental influences.

Traits influenced by polygenic factors are also hereditary and typically exert influence over rather common characteristics. This influence takes place through many gene loci collectively asserting their influence on the trait. Historically, each gene involved was thought to have a minimal effect by itself, with the effect of all genes involved additive. The associated phenotype is rarely discrete and is most commonly continuous or quantitative. Because these traits show a quantitative distribution of their phenotypes in a population, they do not show mendelian inheritance patterns.

Although the use of the term *polygenic* has inferred the effect of multiple genes on the phenotype,

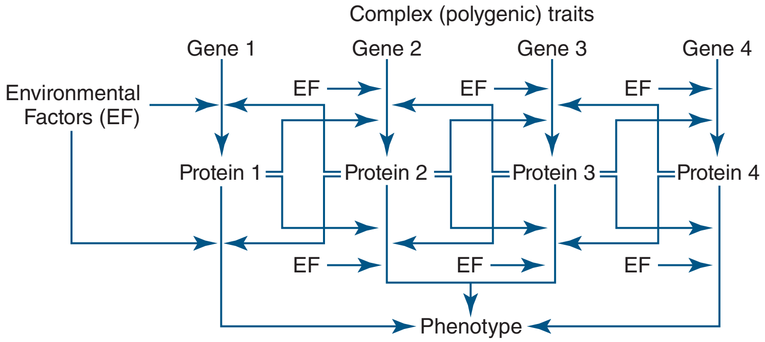

FIGURE 5-5 Unlike Mendelian traits, environmental factors and multiple genes are critical to the development of complex (polygenic) traits. These types of physical traits are continuous rather than discrete (although diseases of this type can still be present or not). Such traits are referred to as quantitative traits or multifactorial because they are caused by some number of genes in combination with environmental factors.[16]

environmental factors can play a variable and generally greater role than in monogenic traits. A change in phenotype depends on the result of the genetic and environmental factors present at a given time. Thus, one may expect that compared with monogenic traits, polygenic traits will be more amenable to change (or a greater change) following environmental (treatment) modification.

Another aspect to consider is the fourth dimension of development—time. Although an environmental modification may alter the development of the phenotype at a particular moment, gross structural morphology, already present, may not change readily unless the environmental modification is sufficient to alter preexisting structure.[12] Examples of polygenic traits include height and intelligence quotient, both of which are continuous traits greatly influenced by genetic factors. However, height and intelligence quotient also can be affected greatly by environmental factors, particularly if they are deleterious.

As polygenic traits are influenced by environmental and multiple genetic factors, they also have been referred to as *multifactorial*, meaning they are influenced by the interaction of multiple genes and environmental factors. However, a distinction from polygenic traits has been made for some multifactorial traits that are discrete (dichotomous). Although polygenic and multifactorial traits are described as resulting from the interaction of multiple genes and environmental factors, the discrete multifactorial traits occur when a liability threshold is exceeded (Figure 5-6). Typically, numerous genes are believed to be involved. Occasionally, though, only a few genes have a major influence on the trait. Their effect on the phenotype is therefore a net effect, not a simple additive one. This leads to a phenotypic expression pattern in a family that approaches that of a discrete mendelian trait and therefore cannot be classed readily as a quantitative trait. The effect of a gene influencing the complex trait may not be to the extent of a gene associated with a monogenic trait but may be referred to as having a major gene effect. Nonsyndromic cleft lip-palate, neural tube defects such as spina bifida and anencephaly, and congenital hip dislocation are examples of multifactorial traits.[17]

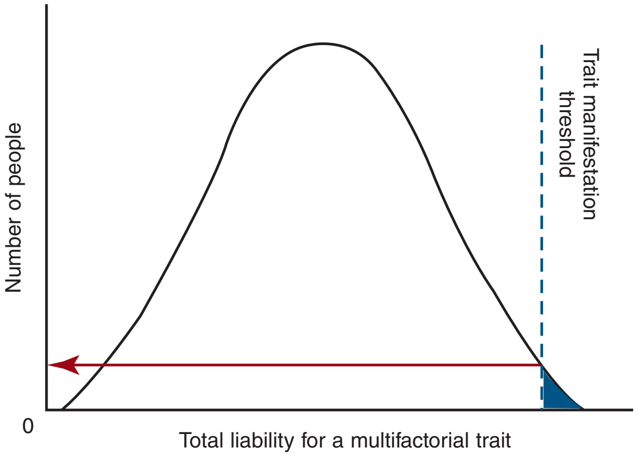

FIGURE 5-6 The liability to have a multifactorial trait is influenced by multiple genes and environmental factors that are distributed throughout a population. However, if some of the population members do not have the trait and some do, then there is a threshold on which a member of the population who has a particular susceptibility to the trait will manifest it. If the genetic liability, environmental liability, or both increase, then the liability distribution curve shifts to the right, increasing the number of persons who are affected.

As mentioned, “mandibular prognathism” has been said to be a polygenic or multifactorial trait that also has been found to fit the criteria of a mendelian trait (autosomal dominant with incomplete penetrance and variable expressivity) in some studies. Even in this group of heterogeneous subtypes, the sagittal length of the mandible, maxilla, or both may be continuous polygenic traits if measured quantitatively and related to each other. However, the alternative is that they are a multifactorial or mendelian discrete trait if the relation of the sagittal length of one jaw relative to the other is deemed sufficient (at the threshold) to state that the mandible is farther anterior relative to the maxilla. Thus, a mandibular prognathism may be skeletally defined mandibular protrusion, maxillary retrusion, or a combination of the two. Analysis of the phenotype and its outcome may depend on the method and endpoint(s) used in the study.

NATURE VERSUS NURTURE

Consideration of which factors influence, determine, or even drive growth and development often has involved a discussion, if not debate, of nature versus nurture, as though it could only be one or the other. However, growth and development are not the result of genetic and environmental (nongenetic or epigenetic) factors working in total absence or independence of others. Full siblings share on average half of their genes, and it is apparent that siblings can have similar occlusions. However, this is in some part environmental (e.g., influenced by dietary and respiratory factors in common) and in some part genetic factors that influence development.[35–37] Indeed, Corrucini[38] points out that the rapid increase in malocclusion comparing industrialized (urban) to nonindustrialized (rural) samples of several disparate populations emphasizes the importance of environmental factors.

Not to be lost in this discussion is the understanding that how the individual responds to environmental changes is influenced by genetic factors. Moss,[8] in a revisitation of the functional matrix hypothesis and resolving synthesis of the relative roles of genomic and epigenetic (environmental) processes and mechanisms that cause and control craniofacial growth and development, concluded that both are necessary. Neither genetic nor epigenetic (environmental) factors alone are sufficient, and only their integrated (interactive) activities provide the necessary and sufficient causes of growth and development. Moss further considered genetic factors as intrinsic and prior causes and what he termed "epigenetic" (environmental) causes as extrinsic and proximate. Most likely for the majority of individuals, the ability to respond to a variety of environmental modifications overlaps considerably. Also expected would be that, if pressured sufficiently, some would respond to a given environmental modification differently or to a different degree than others.

The genetic background of the individual can influence the response to environmental factors, particularly those that are more likely to delineate different individual responses. This is supported by the finding that the differences in shape of the mandibular condyles was "slightly greater" among four different inbred strains of mice on a hard diet than on a soft diet for 6 weeks. [39] When the environment changed sufficiently, the response was different among animals with different genotypes that was not evident before the environmental change. To quote King et al.[40] in regard to human beings, "We propose that the substantive measures of intersib similarity for occlusal traits reflect similar responses to environmental factors common to both siblings. That is, given genetically influenced facial types and growth patterns, siblings are likely to respond to environmental factors (e.g, reduced masticatory stress, chronic mouth breathing) in similar fashions. Malocclusions appear to be acquired, but the fundamental genetic control of craniofacial form often diverts siblings into comparable physiologic responses leading to development of similar malocclusions."

Heritability and Its Estimation

Although the gene-mediated developmental processes bring about basic embryonic development,[41–43] variation from individual to individual is not necessarily the result of genetic variation.[9] Traits are familial ("run" in families), if for whatever reason(s) members of the same family have them. It has been said that parents give not only their genes to their children but also their environment.[44] Traits are heritable only if the familial similarity arises from shared genes. For a quantitative trait, heritability (in the narrow sense) is the proportion of the total phenotypic variance in a sample that is contributed by additive genetic variance. However, the estimated ratio of genetic to environmental variation does not take into account gene–gene (epistatic through their protein products and their effect on gene expression) or gene–environment interaction, as well as other aspects of variation.

Genetic variation is also not a measure of the relative contribution of genes and environment to phenotype or of which part of the phenotype can be attributed to genetic factors and which to environmental factors.[9] For example, one cannot meaningfully say that 3 inches of the radiographic length of a patient's mandible is due to genetic factors, whereas 2 inches is due to environmental factors. To paraphrase Strachan and Read,[44] heritability of a continuous trait actually means heritability of the variations of a continuous trait. The question, "To what extent is a continuous trait (like length of the mandible) genetic?" is a meaningless question. The meaningful, albeit difficult to answer, question is, "How much of the differences in a continuous trait (like length of the mandible) between persons in a particular place at a particular time is caused by their genetic differences, and how much by their different environments and life histories?"

A trait with a heritability estimate of 1 is expressed theoretically without any environmental influence, whereas a trait with a heritability of 0.5 would have half its variability (from individual to individual) influenced by environmental factors and half by genotypic factors. Values greater than 1 may occur because the methodology for estimating heritability in human beings operates under several simplifying assumptions that may be incorrect. One must remember some important aspects of heritability when reviewing them. First, heritability estimates refer to a specific sample and do not necessarily pertain to the situation of a given individual, even from within the sample. Thus, they do not allow one to tell to what degree a particular trait was determined by genetic or environmental factors in a single individual. In addition, heritability estimates are descriptive of variances within a sample at a given time; they are not predictive.[45]

Although the mode of inheritance (e.g., autosomal dominant or polygenic) of a trait is a fixed property in a given individual, heritability is not.[44] Heritability estimates can change with age, as in a longitudinal analysis of 30 sets of siblings who had not undergone orthodontic treatment who showed a significant increase overall in median heritability estimates between the ages of 4 and 14 years for 29 craniofacial skeletal variables, including increases for total anterior face height, upper anterior face height, total posterior face height, and upper posterior face height. Still, despite the general increasing trend in heritability estimates for the craniofacial skeletal variables, a decrease was noted for lower posterior face height. The median estimates of heritability for craniofacial skeletal variables increased from 0.6 at age 4 years to 0.9 at age 14 and 20 years. This is in contrast to the heritability estimates of arch and occlusal variables that decreased from 0.5 at age 4 years to 0.2 and 0.1 at ages 14 and 20, respectively.[46] This study also examined the suggestion that vertical craniofacial variables were influenced more by genetic factors than horizontal craniofacial variables,[1,47–49] finding no significant difference between the vertical and horizontal variable heritability estimates for ages 4, 14, or 20 years.

The heritability of a trait cannot necessarily be extrapolated from one sample and set of environmental conditions to another.[9] An adverse environment can alter the phenotypic expression that the genes would have promoted under more favorable conditions, an extreme example of which is the delayed growth seen from the effects of famine associated with war.[50] Therefore, a high heritability in and of itself does not prevent a trait from being influenced substantially by subsequent changes in environmental conditions in that sample (Box 5-1).[5,9]

Methods to estimate heritability are based on correlations of measurements of the trait between various kinds of pairs of individuals in families, including monozygotic twins, dizygotic twins, parent-child, and sib-sib (sibpair).[51] However, environmental sources of covariance (the effect of those being studied being similar because they are in a similar environment) may be significant and contribute to an inflated heritability estimate.[52] Confirming a certain degree of genetic influence on a trait for a particular sample in a particular environment at a particular time is a preliminary step to further specific genetic linkage studies (using DNA markers) to determine areas of the genome that appear to be associated with the characteristics of a given trait.[45]

BOX 5-1 Heritability (h^2)

Aspects of (additive) heritability in the narrow sense, estimating the effect of an indefinitely large number of genes that all contribute equally to the phenotype. It cannot take into account allele–allele interactions at a gene locus (termed dominance) and gene–gene interactions involving two or more loci (termed epistasis).

- Refers to a specific sample and does not necessarily pertain to the situation of a given individual, even from within the sample
- Is descriptive of variances within a sample at a given time and is not necessarily predictive
- Can change with age
- A different environment can alter the phenotypic expression that the genes would have promoted under other conditions
- A high heritability does not necessarily prevent a trait from being substantially influenced by subsequent changes in environmental conditions in that sample

Craniofacial Skeletal and Dentoalveolar Occlusal Heritability Studies

Consideration of the genetic aspect of occlusal variations and malocclusion has been a major focus of interest to orthodontists. The different studies directed toward heritability of occlusion have varied in method. In addition to environmental covariance, a limitation of many of these studies is that they were based just on twins or siblings who did not receive orthodontic treatment. Possibly, twin pairs and sibships containing one or more treated patients (with moderate to severe malocclusion) were excluded from most studies. Therefore, estimates of genetic and environmental contributions may have been affected by lack of accounting for a common environmental effect[36] and ascertainment bias.[40]

The cause of most skeletal- and dentoalveolar-based malocclusions is essentially multifactorial in the sense that many diverse causes converge to produce the observed outcome.[40] Numerous studies have examined how genetic variation contributes to either or both occlusal and skeletal variation among family members.[1,6,40,46,49,53–71] Many reviews of the genetics of malocclusion actually focus on the cephalometric component of craniofacial form, not on the occlusal component. In most studies (particularly those that try to account for bias from the effect of shared environmental factors, unequal means, and unequal variances in monozygotic and dizygotic twin samples),[10] variations in cephalometric skeletal dimensions are associated in general with a moderate to high degree of genetic variation, whereas in general, variation of occlusal relationships has little or no association with genetic variation.[5]

Although the heritability estimates are low, most of the studies that looked at occlusal traits found that genetic variation has more to do with phenotypic variation for arch width and arch length than for overjet, overbite, and molar relationship. Still, arch size and shape are associated more with environmental variation than with genetic variation.[56] Because many occlusal variables reflect the combined variations of tooth position and basal and alveolar bone development, these variables (e.g., overjet, overbite, and molar relationship) cannot be less variable than the supporting structures. They will vary because of their own variation in position and those of the basilar structures.[46]

The example of reported heritability estimates for anterior and posterior face height and the observed effect of perennial allergic rhinitis and mouth breathing are interesting. Some (although not all) studies suggest that a greater heritability exists for total anterior face height and lower anterior face height than for upper anterior face height and posterior face height. This implies that the greater estimate of heritability for the total anterior face height is due to the greater estimate of lower anterior face height than upper face height. Possibly a lower heritability for the upper anterior face height reflects the effect of the airway, and a lower heritability for posterior face height reflects dietary effects.

How are those findings reconcilable with an increase in total anterior face height and lower anterior face height, in particular, being associated with perennial allergic rhinitis and mouth breathing? One hypothesis is that the lower anterior face height may have a greater heritability than the upper anterior face height in some groups of individuals unless increased nasal obstruction resulting in mouth breathing becomes a predominating factor in group members.[72] Remembering that heritability is a descriptive statistic for a particular sample under whatever environmental conditions existed is essential.

Malocclusion is less frequent and less severe in populations not industrialized (urbanized) and that tend to be isolated. Typically an increase in malocclusion occurs as these populations are "civilized" or become more urbanized. This has been attributed to the interbreeding of populations with, to some degree, different physical characteristics, presumably resulting in a synergistic disharmony of tooth and jaw relationships. This idea was supported by the crossbreeding experiments of Stockard and Anderson[73] in inbred strains of dogs, increasing the incidence of malocclusion, typically caused by a mismatch of the jaws. However, the anomalies they produced have been attributed to the influence of a major gene or genes that have been bred to be part of specific breeds. Considering the polygenic nature of most craniofacial traits, it seems improbable that racial crossbreeding in human beings could resemble the condition of these experiments and thereby result in a synergistic increase of oral-facial malrelations.[6,23,74]

A study of disparate ethnic groups that have interbred in Hawaii found that children of racial crosses are at no increased risk of malocclusion beyond what would have been expected from the usual parental influence. In addition, the increase in malocclusion in populations that have moved recently into an industrialized lifestyle is too quick to be the result of genetic change caused by evolutionary fitness pressure.[74] The most likely explanation for the increased malocclusion seen in "civilization" is changed environment, such as food and airway effects.[38]

Use of Family Data to Predict Growth

Siblings have been noted as often showing similar types of malocclusion. Examination of parents and older siblings has been suggested as a way to gain information regarding the treatment need for a child, including early treatment of malocclusion.[23,24,69,75] Niswander[23] noted that the frequency of malocclusion is decreased among siblings of index cases with normal occlusion, whereas the siblings of index cases with malocclusion tend to have the same type of malocclusion more often. Harris and colleagues[63] have shown that the craniofacial skeletal patterns of children with Class II malocclusions are heritable and that a high resemblance to the skeletal patterns occurs in their siblings with normal occlusion. From this it was concluded that the genetic basis for this resemblance is probably polygenic, and family skeletal patterns were used as predictors for the treatment prognosis of the child with a Class II malocclusion, although it was acknowledged that the current morphology of the patient is the primary source of information about future growth.[75]

Each child receives half of his or her genes from each parent, but not likely the same combination of genes as a sibling unless the children are monozygotic twins. When looking at parents with a differing skeletal morphology, knowing which of the genes in what combination from each parent is present in the child is difficult until the child's phenotype matures under the continuing influence of environmental factors. As Hunter[76] pointed out, with polygenic traits the highest phenotypic correlation that can be expected based on genes in common by inheritance from one parent to a child, or between siblings, is 0.5. Because the child's phenotype is likely to be influenced by the interaction of genes from both parents, the "mid-parent" value may increase the correlation with their children to 0.7 because of the regression to the mean of parental dimensions in their children.

Squaring the correlation between the two variables derives the amount of variation predicted for one variable in correlation with another variable. Therefore, at best, using mid-parent values, only 49% of the variability of any facial dimension in a child can be predicted by consideration of the average of the same dimension in the parents. Only 25% of the variability of any facial dimension in a child can be predicted, at best, by considering the same dimension in a sibling or one parent. Because varying effects of environmental factors interact with the multiple genetic factors, the usual correlation for facial dimensions between parents and their children is about 30%, yielding even less predictive power.[76]

In most patients, the mode of inheritance for the craniofacial skeleton is polygenic (complex). However, in some families (e.g., with a relatively prognathic mandible compared with the maxilla), the mode of inheritance is not polygenic. Future research may investigate the genetic factors that do not fit a polygenic mode that may be present in some families. Identification of those factors will increase the ability to predict the likelihood of a particular resulting morphology.

Unfortunately, orthodontists do not have sufficient information to make accurate predictions about the development of occlusion simply by studying the frequency of its occurrence in parents or even siblings. Admittedly, family patterns of resemblance are frequently obvious, and family tendencies are ignored at the clinician's peril. Nonetheless, predictions must be made cautiously because genetic and environmental factors and their interaction are unknown and difficult to evaluate and predict with precision.

TOOTH SIZE, HYPODONTIA, AND DENTAL ROOT DEVELOPMENT

Additive genetic variation for mesial-distal and buccal-lingual crown dimensions of the permanent 28 teeth (excluding third molars) ranged from 56% to 92% of phenotypic variation, with most over 80%.[77] Estimates of heritability for a number of variables measuring overall crown size of the primary second molars and permanent first molars were moderate to high. Yet less genetic variation was associated with distances between the cusps on each tooth, implying that phenotypic variation for overall crown size was associated more with genetic variation than was the morphology of the occlusal surfaces.[78]

Hypodontia may occur without a family history of hypodontia, although it is often familial. Hypodontia also may occur as part of a syndrome, especially in one of the many types of ectodermal dysplasia, although it usually occurs alone (isolated). Note that "isolated" in this use means not a part of a syndrome, although it still may be familial. Genetic factors are believed to play a major role in most of these cases with autosomal dominant, autosomal recessive, X-linked, and multifactorial inheritance reported.[79] Still, only a couple of genes (*MSX1* and *PAX9*) involved in dentition patterning so far have been found to be involved in some families with nonsyndromic autosomal dominant hypodontia, as well as the *LTBP3* gene, which may also involve short stature and increased bone density in autosomal recessive hypodontia,[80–82] although there are other chromosomal locations that nonsyndromic hypodontia has been mapped to and candidate genes, including 10q11.2 and *KROX-26*.[79,83,84]

A general trend in patients with hypodontia is to have the mesial-distal size crowns of the teeth present to be relatively small (especially if more teeth are missing). The mesial-distal size of the permanent maxillary incisor and canine crowns tends to be large in cases with supernumerary teeth.[85] Relatives who do not have hypodontia still may manifest teeth that are small. This suggests a polygenic influence on the size and patterning of the dentition, with a multifactorial threshold for actual hypodontia in some families.

The presence of a single primary and permanent maxillary incisor at first may appear to be a product of fusion. However, if the single tooth is in the midline and symmetric with normal crown and root shape and size, then it can be an isolated finding or can be part of the solitary median maxillary central incisor syndrome. This heterogeneous condition may include other midline developmental abnormalities of the brain and other structures that can be due to mutation in the *sonic hedgehog (SHH)* gene, *SIX3* gene, or genetic abnormality.[86] Although rare, the development of only one maxillary central incisor is an indication for review of the family medical history and evaluation for other anomalies.

Analysis of the variation in dental age as determined by root development was explained best by additive genetic influences (43%) and by environmental factors common to both twins (50%). Environmental factors unique or specific to only one twin accounted for the remainder. The importance of the common environmental factor was thought to be due to twins sharing the same prenatal, natal, and immediate postnatal conditions that are important for tooth formation.[87]

Incisor mesial distal crown dimensions were found to be small as a part of the extreme form of the Class II, Division 2 malocclusion in which the mandibular incisors are concealed in habitual occlusion, along with strong vertical development of the posterior mandible, forward rotation, and skeletofacial hypodivergence.[88] Following a review of published family pedigrees involving Class II, Division 2 malocclusion, Peck and colleagues[88] noted the probability of autosomal dominant inheritance with incomplete penetrance, although polygenic inheritance was also a possibility.

One of the most common, if not the most common, pattern of hypodontia (excluding the third molars) involves the maxillary lateral incisors. This can be an autosomal dominant trait with incomplete penetrance and variable expressivity as evidenced by the phenotype sometimes "skipping" generations and sometimes being a peg-shaped lateral instead of agenesis and sometimes involving one or the other or both sides.[89] A polygenic mode of inheritance also has been proposed.[90] Unidentified currently, the gene mutation that primarily influences this phenotype has been suggested, in the homozygous state, to influence agenesis of the succedaneous teeth or all or almost all of the permanent dentition.[91,92] In addition, an associated increased agenesis of premolars occurs,[93] as well as with palatally displaced canines.[94]

Maxillary canine impaction or displacement is labial/buccal to the arch in 15% of the cases of maxillary canine impaction and often is associated with dental crowding. The canine impacted or displaced palatally occurs in 85% of the cases and typically is not associated with dental crowding.[95] Palatally displaced canines frequently, but not always, are found in dentitions with various anomalies. These include small, peg-shaped or missing maxillary lateral incisors, hypodontia involving other teeth, dentition spacing, and dentitions with delayed development.[96] Because of varying degrees of genetic influence on these anomalies, there has been some discussion about palatally displaced canines themselves also being influenced by genetic factors to some degree. In addition, the occurrence of palatally displaced canines does occur in a higher percentage within families than in the general population.[97]

A greater likelihood exists of a palatally displaced canine on the same side of a missing or small maxillary lateral incisor, emphasizing a local environmental effect.[98] Also, in some cases, a canine is displaced palatally without an apparent anomaly of the maxillary lateral incisors, and in some cases, lateral incisors are missing without palatal displacement of a canine. Adding to the complexity is the heterogeneity found in studies of cases of bucally displaced canines[99] and palatally displaced canines.[96] Although the canine eruption theory of guidance by the lateral incisor root cannot explain all instances of palatally displaced canines, it does seem to play some role in some cases.[100]

With apparent genetic and environmental factors playing some variable role in these cases, the cause appears to be multifactorial.[101] The phenotype is the result of some genetic influences (directly or indirectly or both, for example, although a primary effect on development of some or all of the rest of the dentition) interacting with environmental factors. Some of these cases may be examples of how primary genetic influences (which still interact with other genes and environmental factors) affect a phenotypic expression that is a variation in a local environment, such as the physical structure of the lateral incisor in relation to the developing canine. Candidate genes that are proposed possibly to influence the occurrence of palatally displaced canines and hypodontia in developmental fields include *MSX1* and *PAX9*.[102]

Investigations so far indicate that a number of heterogeneous genetic factors may be involved in hypodontia. Increased understanding of the various morphogenetic signaling pathways regulating tooth development should allow for induction of tooth development in areas of tooth agenesis.[103] In addition to hypodontia and its primary or secondary relationship to maxillary canine eruption, there are emerging data regarding the influence of genetics on dental eruption. Presently this is most clear in cases of primary failure of eruption (PFE), in which all teeth distal to the most mesial involved tooth do not erupt or respond to orthodontic force. The familial occurrence of this phenomenon in approximately one-quarter of cases facilitated the investigation and discovery of the *PTHR1* gene being involved.[104,105] Advancements in this area could not only help to define patients who are likely to develop or have PFE, but also potentially result in the molecular manipulation of selective tooth eruption rates to enhance treatment protocols on an individual basis.[106]

ENVIRONMENTAL AND GENETIC INFLUENCES ON BILATERAL SYMMETRY

Van Valen[107] described three types of asymmetry: directional, antisymmetry, and fluctuating asymmetry. Directional asymmetry occurs when development of one side is different from that of the other during normal development. The human lung, having three lobes on the right side and two lobes on the left side, is an example of directional asymmetry. Because this may be predicted before development occurs, it is under significant genetic influence. Antisymmetry occurs when one side is larger than the other, but which side is larger varies in normal development and cannot be predicted before development. Antisymmetry is much less common than directional asymmetry. The first two types of asymmetry are considered developmentally normal. Like directional asymmetry, antisymmetry has a significant genetic component that is not fully understood.[108]

Unlike structures that have normal directional asymmetry, facial and dental structures lateral to the midline are essentially mirror images of each other, with the same genetic influences affecting both sides. The conditions are theoretically identical for the trait on both sides of the body because they are developing simultaneously and therefore should develop identically.

One does not find one group of genes for the permanent maxillary right first molar and another group of genes for the permanent maxillary left first molar. The third type of asymmetry, fluctuating, occurs when a difference exists between right and left sides, with which side is larger being random. This reflects the inability of the individual to develop identical, bilaterally homologous structures.[56]

Fluctuating asymmetry has been observed in the primary and permanent dentitions,[109,110] as well as in the craniofacies.[56] The greater amount of fluctuating asymmetry for the distance between cusps on each tooth than for the overall crown size of primary second molars and permanent first molars indicates that the occlusal morphology of these teeth is influenced more by environmental factors than the overall crown size.[78]

The fidelity of developmental symmetry as measured by fluctuating asymmetry is an indirect measure of environmental stress so that differences between bilateral structures are due predominantly to environmental factors.[111] An individual's level of fluctuating asymmetry is an indicator of how well the genome can produce the ideal phenotype under certain circumstances. However, not everyone's genome can do as well producing the ideal phenotype under certain circumstances. Therefore, Moller and Pomiankowski[112] propose that fluctuating asymmetry may be used as an indication of an individual's "ability to cope with its environment." Sprowls et al.[113] reported a previously unreported association between decreased developmental stability (evident in increased fluctuating asymmetry), arch form discrepancies, and anterior maxillary dental crowding. Although heritability (*h*2) estimations that include environmental covariance for dental position, rotation, and angulation collectively suggest that the predominant source of occlusal variation is environmental, they suggested that a variable component of occlusal variation may be the individual's relative ability to develop right and left mirror images, which has experimentally been associated with gene–gene interaction that (*h*2) does not measure.

INVESTIGATING THE GENETIC BASIS FOR VARIABLE RESPONSE TO TREATMENT

Increased understanding of the various morphogenetic signaling pathways regulating development of the craniofacies should allow for the manipulation of the proliferation, patterning, and differentiation of tissue to treat skeletal discrepancies that contribute to malocclusion.[103] An important aspect of this is increased comprehension of how epigenetic (including environmental or treatment) factors affect expression of genes that influence postnatal growth.[114] Because the relative influence of genetic factors on development of an occlusion does not necessarily determine the response to treatment, and the ability to predict abnormal growth is usually of limited specificity in reference to an individual when looking at family members, the future of genetics in orthodontics primarily will involve analyzing the genetic basis for variable response to treatment. In other words, are there genetic factors that influence the response to treatment? If so, what are they? Can they be identified before treatment to assist in devising the most effective and efficacious treatment, including the avoidance of unwanted responses?[115]

GENETIC FACTORS AND EXTERNAL APICAL ROOT RESORPTION

Analysis of the genetic basis for variable response to treatment has been applied to the specific adverse outcome sometimes associated with orthodontic treatment called external apical root resorption (EARR). The degree and severity of EARR associated with orthodontic treatment are multifactorial, involving host and environmental factors. An association of EARR exists, in those who have not received orthodontic treatment, with missing teeth, increased periodontal probing depths, and reduced crestal bone heights.[116] Individuals with bruxism, chronic nailbiting, and anterior open bites with concomitant tongue thrust also may show an increased extent of EARR before orthodontic treatment.[117]

EARR is also increased as a pathologic consequence of orthodontic mechanical loading in some patients.[118,119] The amount of orthodontic movement is positively associated with the resulting extent of EARR.[120–122] Orthodontic tooth movement, or "biomechanics," has been found to account for approximately one-tenth to one-third of the total variation in EARR.[123–125] Owman-Moll and coworkers[126] showed that individual variation overshadowed the force magnitude and the force type in defining the susceptibility to histologic root resorption associated with orthodontic force. Individual variations were considerable regarding both extension and depth of histological root resorption within individuals, and these were not correlated to the magnitude of tooth movement achieved.[127]

There is considerable individual variation in EARR associated with orthodontic treatment, indicating an individual predisposition and multifactorial (complex) etiology.[128–133] Heritability estimates have shown that approximately half of EARR variation concurrent with orthodontia, and almost two-thirds of maxillary central incisor EARR specifically, can be attributed to genetic variation.[133,134] A retrospective twin study on EARR found evidence for both genetic and environmental factors influencing EARR.[135] In addition, studies in a panel of different inbred mice supported a genetic component involving multiple genes in histologic root resorption.[136,137]

While there is a relationship between orthodontic force and root resorption, it is against the backdrop of previously undefined individual susceptibility. Because mechanical forces and other environmental factors do not adequately explain the variation seen among individual expressions of EARR, interest has increased on genetic factors influencing the susceptibility to EARR. The reaction to orthodontic force, including rate of tooth movement, can differ depending on the individual's genetic background.[133,134,138,139]

Variation in the interleukin-1β gene (*IL-1B*) in orthodontically treated individuals accounts for 15% of the variation in EARR. Persons in the orthodontically treated sample who were homozygous for *IL-1B* +3953 (previously designated as +3954) SNP *rs1143634* allele "1" were estimated to be 5.6 times (95% confidence interval, 1.89–21.20) more likely to experience EARR of 2 mm or more than were those who were heterozygous or homozygous for allele "2" ($p = .004$).[140] Investigators in Brazil followed essentially the same protocol except for using periapical instead of lateral cephalometric radiographs for pretreatment and posttreatment measurements and also found this genetic marker to be significantly associated with EARR concurrent with orthodontic treatment[141] (Table 5-1 and Figure 5-7).

TABLE 5-1 External Apical Root Resorption of Maxillary Central Incisors of 2 mm or Greater Compared by IL-1B +3953 (+3954) SNP rs1143634 Genotype

	1,1	1,2	2,2
Indiana			
Affected	12 (71%)	20 (38%)	0
Unaffected	5 (29%)	32 (62%)	4 (100%)
Brazil			
Affected	11 (65%)	7 (37%)	5 (20%)
Unaffected	6 (35%)	12 (63%)	20 (80%)
Combined			
Affected	23 (68%)	27 (38%)	5 (17%)
Unaffected	11 (32%)	44 (62%)	24 (83%)

Number affected or unaffected for each genotype and percentage of total for that genotype in each cell. The protocols for the independent investigations in Indiana and Brazil were essentially the same, except the Indiana measurements were from lateral cephalometric radiographs and the Brazilian measurements were made from periapical radiographs.[140,141]

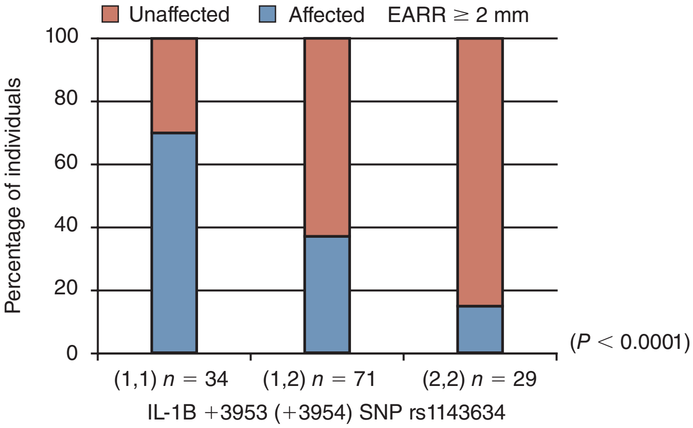

FIGURE 5-7 Percentage of orthodontic patients with 2 mm or more of external apical root resorption (EARR) by IL-1B +3953 (previously designated as +3954) SNP rs1143634 genotype combining the data from Table 5-1.[140,141]

Note that in keeping with EARR concurrent with orthodontic treatment being a multifactorial/complex trait, although this genetic marker is associated with the trait occurring most of the time, there are patients who have the DNA marker that usually accompanies EARR who do not have EARR and there are some patients with EARR who do not have the marker, so the "predictive" value of this single marker is limited by itself, without information about other DNA (gene) markers and other variables that may be involved.

Interestingly, Iwasaki et al.[142] found individual differences in a ratio of IL-1β to IL-1RA (receptor antagonist) cytokines in crevicular fluid that correlated with individual differences in canine retraction using identical force. Although the relation to genetic markers was not undertaken, this study indicates a variable individual response to orthodontic force that may be mediated at least in part by IL-1β and IL-1RA cytokines. This supports the hypothesis that bone modeling mediated, at least in part, by IL-1β as an individual response to orthodontic force can be a factor in EARR. A large number of other genes and their proteins that affect bone physiology could also be involved in the rate of tooth movement, as well as EARR.[138]

Further testing of another candidate gene using nonparametric sibling pair linkage analysis with the DNA microsatellite marker D18S64 (tightly linked to the gene *TNFRSF11A*) identified evidence of linkage (LOD = 2.5; $p = .02$) of EARR affecting the maxillary central incisor.[143] This indicates that the *TNFRSF11A* locus, or another tightly linked gene, is associated with EARR. The *TNFRSF11A* gene codes for the protein RANK, part of the osteoclast activation pathway.[144] Future estimation of susceptibility to EARR likely will require the analysis of several genes as mentioned previously, root morphology, skeletodental values, and the treatment method to be used, or essentially the amount of tooth movement planned for treatment.[134,145]

PAIN PERCEPTION AND TEMPOROMANDIBULAR DYSFUNCTION

Temporomandibular dysfunction (TMD) can be broadly classified as somatic and neuropathic, although the individual etiologies within each category are heterogeneous and probably often complex. Genetic factors may play a role in TMD by influencing variation in individual pain perception, sex and ethnicity, production of proinflammatory cytokines, the breakdown of extracellular matrix, by other proteins from genes expressed in the TMJ, and as a part of some genetic syndromes.[146] Although relationships between genetic variants and disease can be investigated using family aggregation studies where clusters of disease within genetically related family members are analyzed, to date, family-aggregation studies have failed to identify a genetic influence on TMD.[147]

These types of studies may have been "underpowered," meaning that they did not have a sufficient number of subjects to be effective in this type of analysis. Interestingly in 2003, Zubietta et al.[148] reported that a common variant of the gene that codes for the enzyme catechol-*O*-methyl-transferase (*COMT*) was associated in humans with diminished activity of pain regulatory mechanisms in the central nervous system. Instead of genetic family-aggregation (twin) studies, Slade et al.[147] pursued genetic association studies, using traditional epidemiologic study designs in which risk of disease was contrasted among subgroups (TMD affected versus unaffected) based on common allelic (DNA) variants (markers).

Their 3-year prospective study of 202 healthy women (18 to 34 years old) who did not have TMD when examined at baseline (none of whom were in orthodontic treatment at the time, although 99 had a history of orthodontic treatment) found that TMD onset was 2.3-fold greater for subjects who had only high pain sensitivity (HPS) and/or average pain sensitivity (APS) haplotypes based on *COMT* genetic variation, compared with subjects who had one or two low pain sensitivity (LPS) haplotypes.

What about the women who had a history of orthodontic treatment? Of 174 available for analysis, there were 15 (8.6%) new cases of TMD. The risk of TMD was 3-fold greater among subjects who reported a history of orthodontic treatment compared with those who did not, although the associated relative risk was not statistically significant (95% confidence interval, 0.89–10.35). However, although in the subjects who had *COMT* pain-resistant haplotypes, there was no difference in having a history of orthodontics; in the subjects with pain-sensitive haplotypes, there were significantly ($p = .04$) more individuals with a history of orthodontia who developed TMD than there were those who developed TMD and had no history of orthodontia.[147]

It was noted that statistically significant elevation in risk is not sufficient evidence that an attribute (in this case, orthodontic treatment) is causal, although it does bring up the question of whether patients with pain-sensitive haplotypes experience relatively greater discomfort or pain when undergoing procedures used during fixed orthodontic treatment. It should also be noted that in this study the experience of orthodontic treatment was assessed merely by asking subjects a single question, and there was no attempt to clarify whether fixed orthodontic treatment, duration of the treatment, or other treatment such as surgery was involved.

Any etiologic role of orthodontic treatment in this study would require that the putative causal effect of orthodontic treatment was one that persisted after completion of treatment yet did not cause the person to develop TMD at the time of recruitment. This raises the possibility that there was yet another environmental interaction that occurred in the time between completion of orthodontic treatment and enrollment in the study. Still, it is an intriguing outcome, and one that needs to be further investigated.

HUMAN GENOME PROJECT AND BEYOND

The Human Genome Project resulted in not only a single human genome sequence composed of overlapping parts from many human beings but also a catalog of some 1.4 million sites of variation in the human genome sequence. This increased number of variations (or polymorphisms) may be used as markers to perform genetic (including genetic–environment interaction) analysis in an outbred population such as human beings. The human genome varies from one individual to the next most often in terms of single-base changes of the DNA, called *single nucleotide polymorphisms* (*SNPs*, pronounced “snips”). The main use of this human SNP map will be to determine the contributions of genes to diseases (or nondisease phenotypes) that have a complex, multifactorial basis. Likewise, the development of the Mouse Genome Project will increase the number of known DNA markers that may be used in the study of putative relevant genetic factors and genetic–environmental interactions, which then may be tested for in the human population. Although the scale of such studies could be daunting and there are still problems to solve, their potential for studying how natural variation leads to each one of our qualities is significant. They may be the best opportunity yet to understand the roles of nature and nurture (including treatment), rather than nature versus nurture, in development.[72,149]

Heritability estimates can indicate how much of the phenotypic variation is associated with genetic variation, a consideration in the feasibility of a search for identifying the genetic factors. The search for DNA markers linked with certain phenotypes may indicate areas of the genome that have a gene or genes that influence the phenotype. The DNA marker does not necessarily define precisely what gene in the area is contributing or what allele of that gene may be more influential than others. Nonetheless, the search for markers linked with certain phenotypes can indicate areas of the genome that contain influential genes that previously were not known or even suspected to have an influence on the phenotype. Once a particular gene (or genes) in an area of the genome is identified, it becomes a candidate gene for specific analysis of its structure to pinpoint the relevant allele(s).

The study of the effect of particular genetic factors on development also may be done using a candidate gene chosen because of its function, or the function of an associated protein, instead of using DNA markers to see what genes may be linked with a phenotype. This was the approach in a study of the association of the Pro-561Thr (P56IT) variant in the growth hormone receptor gene (*GHR*), which is considered to be an important factor in craniofacial and skeletal growth. Of a normal Japanese sample of 50 men and 50 women, those who did not have the *GHR* P56IT allele had a significantly greater mandibular ramus length (condylion-gonion) than did those with the *GHR* P56IT allele. The average mandibular ramus height in those with the *GHR* P56IT allele was 4.65 mm shorter than the average for those without the *GHR* P56IT allele. This significant correlation between the *GHR* P56IT allele and shorter mandibular ramus height was confirmed in an additional 80 women.[150]

Interestingly, the association was with the mandibular ramus height but not mandibular body length, maxillary length, or anterior cranial base length. This suggests a site-, area-, or region-specific effect. The study concluded that the *GHR* P56IT allele may be associated with mandibular height growth and can be a genetic marker for it. Still, whether the effect is directly on the mandible or some other nearby tissue or on another matrix is not clear. To see what effect different diets would have on individuals with and without the *GHR* P56IT allele would be interesting as a means of looking at genetic and environmental factor interaction. Undoubtedly many other genes that may influence craniofacial structure, including ramus height, could be identified, and their variation could be studied along with different environmental (treatment?) factors and the resulting phenotype.

SUMMARY

Because of the presumption that malocclusions with a "genetic cause" are less amenable to treatment than those with an "environmental cause," some investigators and clinicians would like an unambiguous answer to the question of whether a patient's malocclusion is the result of genetic or environmental factors. However, the pattern of growth and development is typically the result of an interaction between multiple genetic and environmental factors over time. Thus the malocclusion seen in most patients is of polygenic/multifactorial cause. This does not mean that specific malocclusions are not influenced heavily by single genes that have large effects.[23] Even for monogenic traits and syndromes, evidence exists for the influence of other genes and environmental factors, although the monogenic influence is particularly strong.

Because of varying methods used and the nature of heritability estimates, a range of values exists for craniofacial skeletal and dentoalveolar structures. Heritability tends to explain insufficiently the variation seen among family members. The use of family data is of qualitative more than quantitative use in predicting the growth of an individual family member. In general, heritability estimates for craniofacial skeletal structures tend to be greater than those for dentoalveolar (occlusal) traits. Hypodontia is an exception to the general tendency for occlusal traits to have low heritability estimates. Apparently, some genetic influence affects palatally displaced canines, in some cases at least, partially through an effect on the development of the lateral incisors.

The fidelity of developmental symmetry as measured by fluctuating asymmetry is a measure of environmental stress. Thus differences between mirror image bilateral structures are due to environmental factors. The ability of the patient to buffer the effect of environmental factors on development of bilateral mirror image structures has a strong genetic component.

Contrary to the presumption that malocclusions of "genetic cause" are less amenable to treatment than those of an "environmental cause," a change in environmental factors can affect a polygenic trait with a high estimate of heritability. The effect depends on the response of the patient to the change in environment (e.g., treatment). Not all individuals will have the same capacity to respond to the change in environment, although there may be considerable overlap. The capacity of an individual to respond to a change in environment influenced by genetic factors is of more importance clinically than the relative influence genetic variation has on phenotypic variation before treatment. In the future, orthodontists' ability to treat patients better will depend on investigations into how environmental factors affect gene expression that influences malocclusion. An important variable is the role that individual genetic variation has on the response to treatment, which is directed at a specific environmental change.

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CHAPTER 6

The Upper Airway and Cranial Morphology

Brian Preston

OUTLINE

Comparative Anatomy
  Bipedal Stance
  Cranial Base
  Pharyngeal Regions
  Cranial Posture and Balance
Natural Head Position
  Hyoid Triangle
  Cervical Posture, Respiration, and Dental Occlusion
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Mode of Respiration and Cranial Morphology
  Cephalometrics of the Upper Airway
  Growth of the Nasopharynx
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  Surgery and the Upper Airway
Summary

COMPARATIVE ANATOMY

Bipedal Stance

The evolution of an upright posture and bipedal walking has been associated with notable changes that characterize many human bones and muscles. In the course of developing an upright posture, the spinal column and skull (axial skeleton), the pelvis and legs, and all of the related joints, ligaments, and muscles changed to accommodate the newly attained upright posture and bipedal stance of the human being.[1] Accordingly, the spine developed secondary curves in the lumbar and cervical vertebrae; the size of the vertebrae increased from the top down; the rib cage flattened; and the change in the relative size of the cranium and jaw allowed the balance of the head to shift backward, requiring less powerful muscles on the back of the neck (Figure 6-1).

Cranial Base

In the center of the most noteworthy anatomic changes that accompanied the development of a bipedal stance is the cranial base. In this sense, paleontologists and orthodontists deal with the same fundamental problem—to understand craniofacial morphogenesis (1) during phylogenesis and (2) during ontogenesis. At the same time, the mechanisms involved in facial morphogenesis remain the object of debate between the "functionalists" and the "structuralists" who believe that the inherited genetic pattern overrides the influences of function.[2–4] In light of new research, the objective of this section is to show the importance of understanding the forces within the cranial base that drive facial growth, specifically prior to the age of 6 years. Architecturally, the cranial base provides the platform on which the brain grows and around which the face develops. In addition, the cranial base connects the skull with the vertebral column and with the mandible, and in this role it is able to influence craniofacial morphology.

The midsphenoidal synchondrosis marks the division between the anterior and posterior portions of the cranial base that are embryologically distinct and that grow somewhat independently. During the fetal period in human beings and nonhuman primates, the midline anterior cranial base grows in a pattern of positive allometry relative to the midline posterior cranial base.[5] The anterior cranial base lengthens in concert with the frontal lobes of the brain, reaching about 95% of its adult length by 6 years in human beings. The more inferior portions of the anterior cranial base continue to grow as part of the face after the neural growth phase has been

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completed, forming the ethmomaxillary complex that grows downward and forward, mostly through drift and displacement.[6]

Human beings have a more flexed cranial base than do other primates, but it is not always understood that the human cranial base flexes postnatally, whereas the nonhuman primate cranial base extends during this same period.[7] The spheno-occipital synchondrosis, which remains active until after eruption of the second permanent molars, is probably the most active synchondrosis in generating cranial base angulation in primates.[8] Some evidence shows that a degree of independence exists between the growth and size of the brain and the cranial base angle during development.[9] What is known is that the human brain flexes rapidly soon after birth, almost entirely before 2 years of age, and well before the brain has ceased to expand appreciably (Figure 6-2). Ontogenetic data suggest that a large proportion of the variation in cranial base angle among primates also must be related to variation in aspects of facial growth. A close relationship has long been known to exist between the growth of the cranial base and the growth of the face, but many details of how these regions interact remain poorly understood. Although the face has some influence on cranial base growth, there are good reasons to believe that the cranial base exerts a greater influence on the face than vice versa.

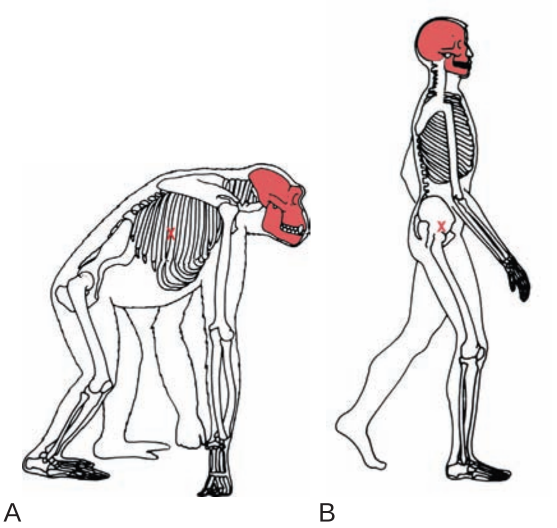

FIGURE 6-1 In apes **(A)** the center of mass of the cranium is located well ahead of the center of mass (*X*) of the body. In the course of development of an upright posture, the center of mass of the human cranium **(B)** came to lie close to the vertical central axis of the body. This axis runs through the center of the pelvic girdle (*X*). Apes require strong posterior cervical muscles to maintain their cranial posture and visual axis orientation, whereas in human beings, relatively smaller rectus muscles are able to perform these duties.

With the advent of volumetric radiography, it has become possible to gain greater insight into craniofacial growth and development. An ongoing high-resolution digital radiographic study of 249 white children under the age of 6 years resulted in a basic three-dimensional (3D) cranial analysis.[10–12] Two transverse cranial measurements—the distance between the left and right pterygoid plates (Pti points) and the distance between the left and right temporal condylar points (CT points)—were added to specific landmarks located on the basicranium to constitute a basic 3D cranial analysis (Figures 6-3 and 6-4). The objectives of the Cranexplo (Telecrane Innovation, Merville-Franceville, France) analysis were to analyze the ontogenetic process of cranial base flexion and to describe how this contraction process operates in a 3D framework (see Figure 6-4). The work carried out by Deshayes and Deshayes et al. shows that during basicranial flexion, the cranial base shortens and widens, the vault increases in height, and the sphenoidal angle closes.[13,14] Basion moves closer to the pterygoid plates due to a bone remodeling that results in a clockwise rotation of the occipital and an anticlockwise rotation of the sphenoid bone (Figure 6-5). The process of cranial base flexion is accompanied by a remodeling of the bilateral temporal bones, which results in a widening of the cranial base (Figures 6-6 and 6-7). The degree of and direction of rotation of the occipital and sphenoid bones

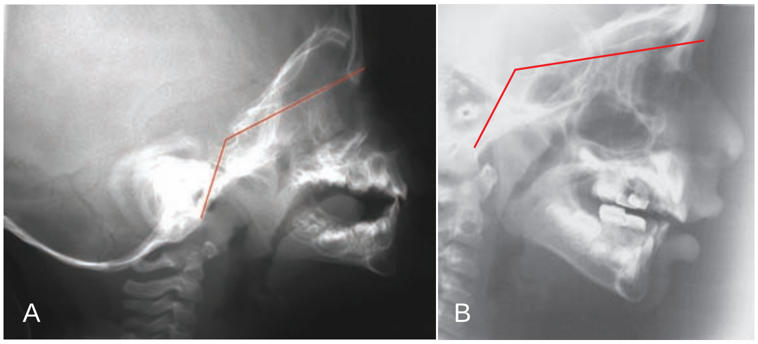

FIGURE 6-2 Sagittal cephalometric radiographs taken at 6 months **(A)** and at 5 years **(B)** of age. At 5 years the cranial base is more flexed (127 degrees) than at the earlier age (135 degrees), and with age a greater increase in the length of the posterior cranial base has occurred than in the anterior cranial base.

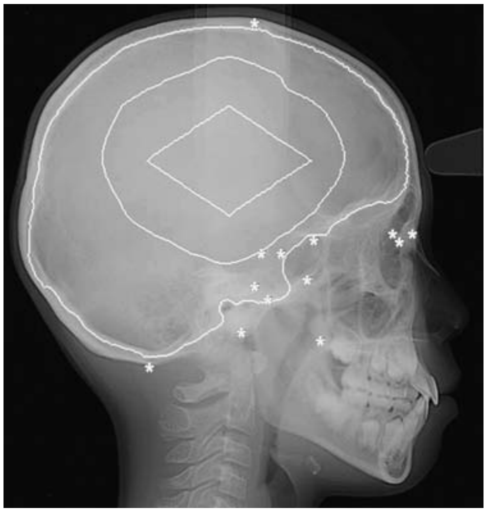

FIGURE 6-3 Localization of the cranial landmarks for the Cranexplo Analysis. Matrices were set up to locate the cranial landmarks mathematically, and these locations were then compared with the same landmarks determined by experts in cephalometric tracing.[10–12]

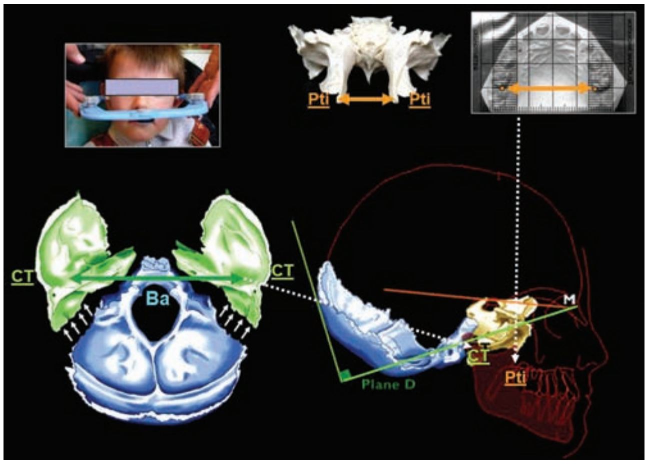

FIGURE 6-4 The three-dimensional cephalometric analysis (Cranexplo analysis) and the two exocranial measurements (CT left to CT right and Pti left to Pti right).[10–12]

tends to vary during the first 6 years of life.[12–14] Individuals with a narrow cranial base (dolichocephalic) tend to have a greater clockwise rotation of their occipital bones that, in turn, tends to keep their cranial base narrow. If, in addition, these individuals develop a tendency for an anticlockwise rotation of their sphenoid bones, they will tend to have narrower faces with an increase in depth of their maxillary arches (Figure 6-8). A combination of a clockwise occipital and an anticlockwise sphenoidal rotation leads to a tendency to develop a relative maxillary protrusion (Class II). In contrast, individuals with a wider cranial base tend to display an increase in the anticlockwise rotation of their occipital bones in combination with a greater degree of clockwise rotation of their sphenoid bones. It may be expected that these individuals would tend to display a relative widening and shortening of their maxillary arches (Class III) (see Figure 6-8).

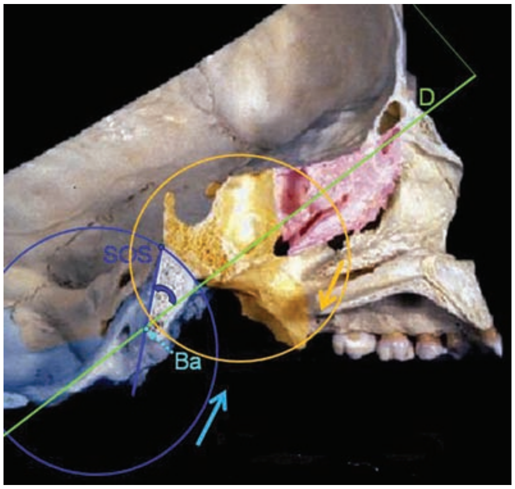

FIGURE 6-5 The principle of ontogenetic flexion. The cranial base flexes when bone remodeling results in an anticlockwise rotation of the occipital bone and in a clockwise rotation of the sphenoid bone.[12,13]

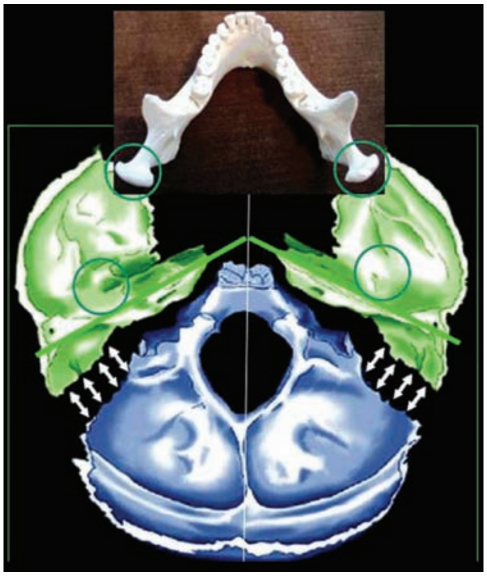

FIGURE 6-6 As a result of the positive remodeling of the occipital bone, a widening of the cranial base occurs as the angle between the two petrous portions of the temporal bones becomes more obtuse.[13,14]

It is important to note that the individual bony units of the cranial base can remodel somewhat independently, which leads to the discovery that the flexion of the cranial base may be associated with different types of bone remodeling. As an example, the presphenoid and basisphenoid bones may both grow with either a clockwise or an anticlockwise rotation, independently of each other. This finding may explain why it is possible to find a specific cranial base angle in either a Class II or Class III malocclusion.

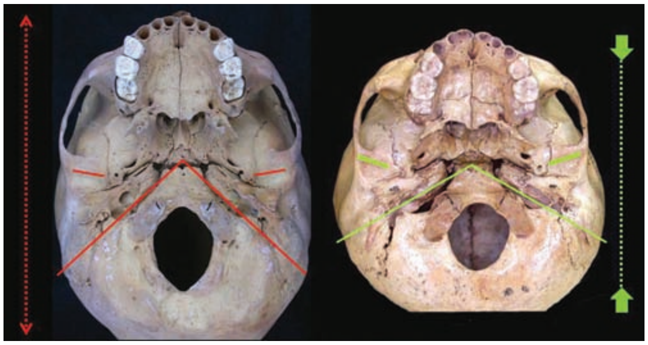

FIGURE 6-7 The slightly flexed cranial base (*red*) is long with a narrow and long maxillary arch. The more flexed cranial base (*green*) presents with widening and shortening of the maxillary arch. It should be noted that the location of the temporomandibular joints will also be affected by these changes in cranial base flexion.[12–14]

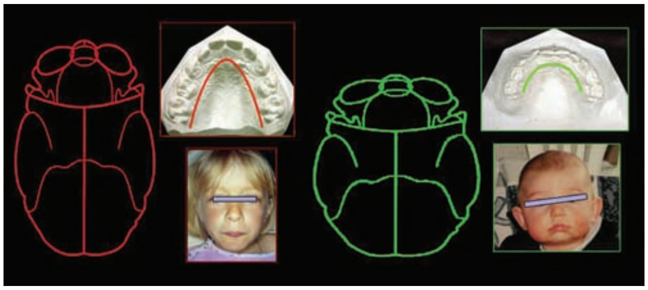

FIGURE 6-8 In the *red skull*, a negative sphenoidal remodeling results in a narrow maxillary arch; the negative occipital remodeling keeps the cranial base narrow and places the temporo-mandibular joints in a more retruded position. The *green skull* illustrates how a positive sphenoidal remodeling gives a widening of the maxillary arch. The positive occipital remodeling gives a widening of the basicranium and a forward positioning of the temporomandibular joints.[12–14]

Up to the end of the first year of life, the intrasphenoidal synchondrosis defines the junction of the anterior and posterior portions of the midline cranial base. During this period, the sphenoidal angle can also flex around this synchondrosis. There exists a complex "competition" between the anterior and the posterior parts of the basicranium, which induces an important variability in the reshaping of the basicranium that Deshayes and colleagues refer to as the "mosaic" of basicranial flexion.[12–14]

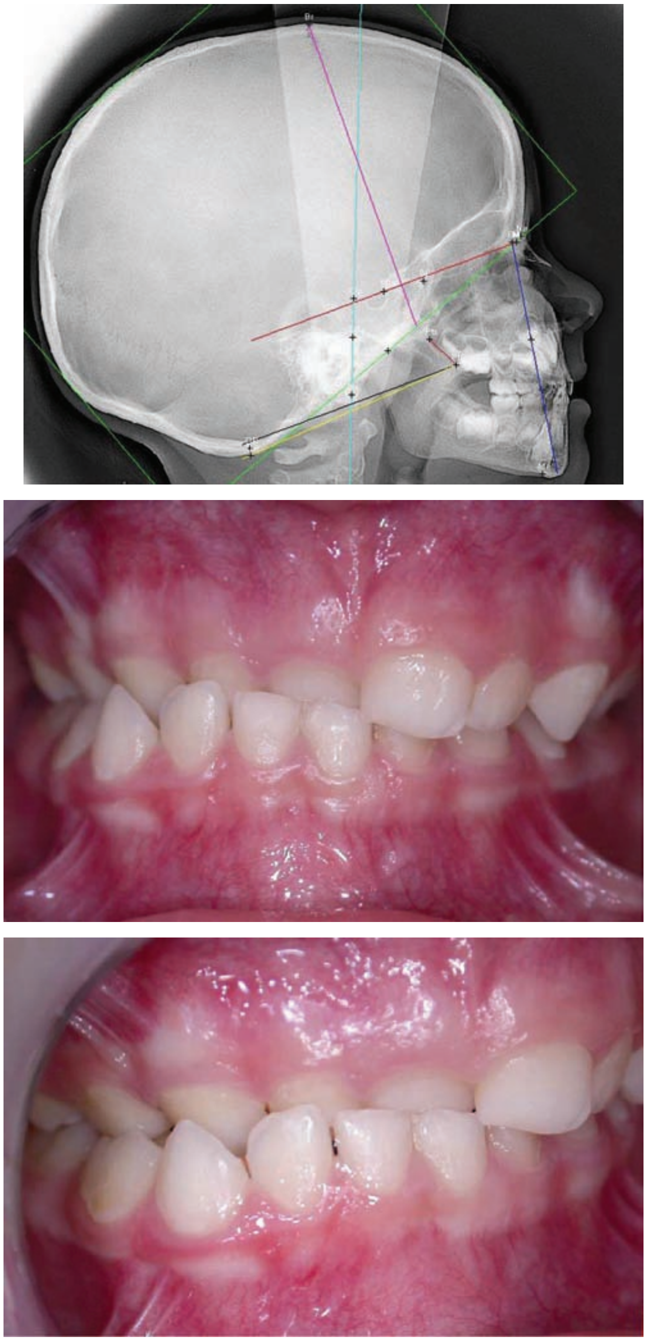

FIGURE 6-9 Antoine (4 years) with a Class III malocclusion and with an excessively flexed basicranium (sphenoidal angle = 111 degrees).

By identifying at a young age the small disharmonies that exist within the cranial base, it becomes possible to discern the genetic cranial pattern, relative to the ontogenetic process of flexion, and the malocclusion that may result from these disharmonies. It is understood that after birth, the development of facial functions such as breathing, chewing, and swallowing will affect the mosaic of cranial bone remodeling. During the first 6 years of life, the facial dynamics start to compete with the cranial dynamics. The eruption of the first permanent molars usually coincides with the stage at which the cranial dynamics is ending. This implies that the diagnosis of abnormalities of cranial base flexion should be done at an early age (Figures 6-9 and 6-10).

Flexion of the anterior cranial base and face relative to the posterior cranial base not only rotates the face under the anterior cranial fossa but also shortens the depth of the pharyngeal space that exists between the back of the palate and the front of the vertebral column. One suggestion is that there must be functional constraints on how far back the palate can be positioned without occluding the airway.

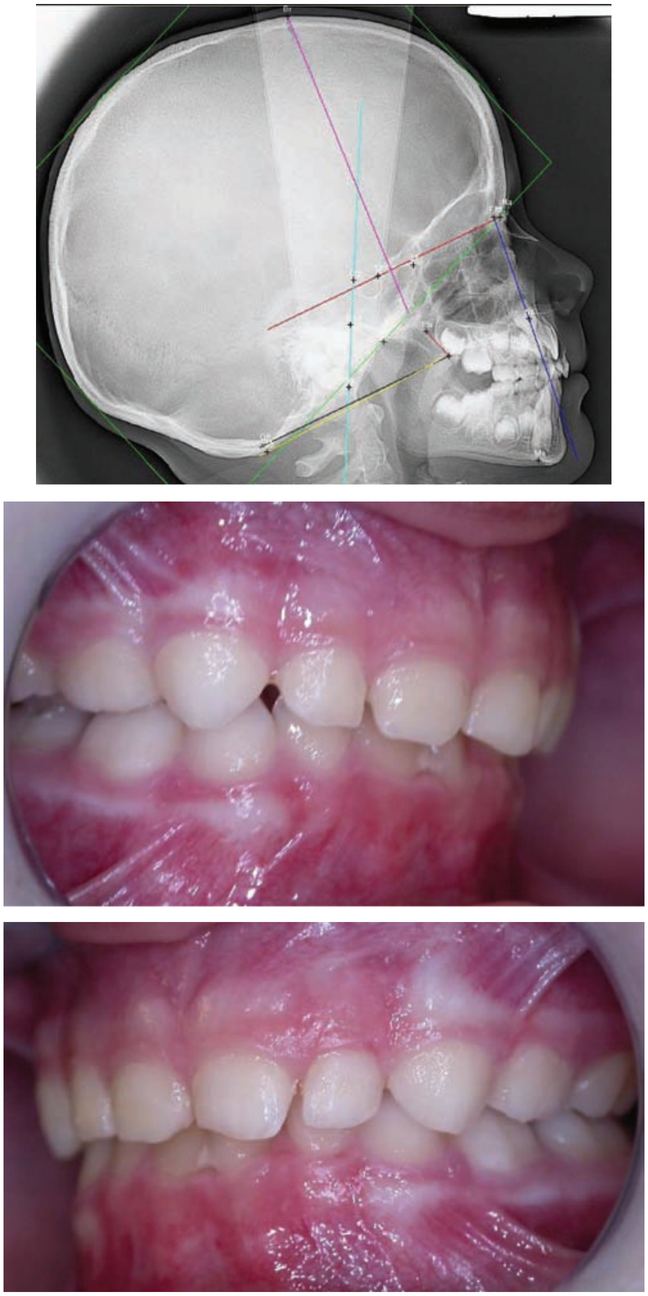

FIGURE 6-10 After 8 months of treatment the anterior crossbite has been corrected and the sphenoidal angle has been increased to 117 degrees.

Pharyngeal Regions

Human beings have a unique pharyngeal configuration in which the larynx lies well below the oral cavity, so that the trachea and esophagus share a common passageway.[15] The low position of the larynx provides the physiologic basis for human speech because it creates a two-tube supralaryngeal vocal tract. In human beings, the vertical and horizontal cross-sectional dimensions can be modified independently by roughly 10-fold to produce vowels that are acoustically distinct regardless of vocal tract length. In contrast, nonhuman primates and human newborns tend to have larynges that are situated higher in the throat, and they would find it difficult to speak because the relative extra length of their oral cavity prevents the vocalization of consonants. The added length of their oral cavity is associated with differences in the lingual musculature and in the relative position of the hyoid bone. The hyoid bone, which, in human beings, is positioned higher and farther back than in apes, allows for more precise and efficient control of the tongue. To produce articulate speech, human beings also have had to develop an ability to control their intercostal muscles with the precision required to allow simultaneous speech and breathing.

Cranial Posture and Balance

Reference has been made to the location of the center of mass of the body in relationship to the evolution of the upright posture of human beings.[16,17] Closely related to the posture of the body is the poise of the skull on the cervical spine, where it is maintained in an upright posture by muscles and ligaments under tension. Others suggest that an erect posture has allowed the weight of the head to be borne directly by the neck vertebrae with a consequent reduction in the role of the nuchal muscles[18] (Figure 6-11).

The posture of the head is influenced primarily by the force of gravity, but nevertheless the physiologic demands of respiration, sight, balance, and hearing also must affect cranial deportment.[19] Solow and Tallgren[20] and Posnick[21] showed that statistical correlations exist between the predominant mode of respiration, head posture, and some facial features. Such findings are not unique, and others reported similar observations, which indicate that abnormal and prolonged changes in cranial posture during growth and maturation may have an effect on the expression of facial form.[22–26] Research indicates that a lateral inclination of the occlusal plane affects cranial and general posture because it induces cervical spine displacement and an asymmetric stress distribution in this area.[27]

Several investigators have changed head posture experimentally by altering, for example, nasal airflow, mandibular position, or tongue posture and deglutition.[19,28–31] When weights as light as 50 g are attached to the heads of living subjects, their head posture is modified with relative ease, but this response is unpredictable within individuals and between individuals.[28] Geometric calculations have been used to locate the center of gravity of isolated crania.[16,32–34] Such calculations suggest that in human beings the center of gravity of the head lies just anterior to the occipital condyles.[35,36] These determinations differ from the observations of Schultz,[37] who in his sample of two heads identified a center an average of 31 mm forward of the vertical midline of the occipital condyle. Establishing the anatomic position of the center of gravity in the different morphologic craniofacial types

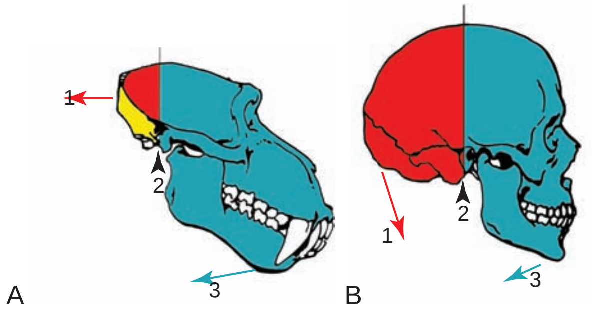

FIGURE 6-11 In apes **(A),** the fulcral point of the head (*2*) is located relatively far posteriorly in the skull, necessitating strong posterior cervical muscles (*1*) to maintain the balance of the head on the occipital condyles. In human beings **(B),** the occipital condyles (*2*) are located closer to the middle of the skull, which allows for weaker postvertebral cervical muscles (*1*) to balance the head and to counteract the pull of the suprahyoid muscles (*3*) (see Chapter 11).

may be of real value to help in the understanding of how variations in head posture may be associated with and perhaps influence craniofacial growth and development.

Orthognathic surgery to advance or retract the mandible will change the center of gravity of the head and the spatial relationships of the suprahyoid cranial structures, both of which have been associated with changes in head posture.[38] One year after surgery, a statistically significant head flexion was observed in a combined maxillary intrusion and mandibular advancement group, and with maxillary intrusion plus mandibular setback was a trend toward persistent cranial extension. In a group of patients who underwent mandibular surgery for the correction of mandibular prognathism, the results showed an increase in cranial extension (mean, 2.7 degrees) and a mean reduction in airway space.[39] Altered cranial posture, such as has been observed in individuals who have undergone orthognathic surgery, will alter the force vectors that result from the interaction of the center of mass of the skull, its fulcral axis, and gravitational pull (Figure 6-12).

NATURAL HEAD POSITION

The inherent variability of intracranial cephalometric reference structures makes analysis based on them potentially misleading, with serious implications for orthodontic and orthognathic surgical treatment planning.[40,41] Variations in the location of cranial landmarks can confound cephalometric interpretation when they are combined with nonstandardized cephalometric techniques. Obtaining a standardized orientation of the head, referred to as natural head position, is possible by focusing on a distant point.[42] Following the introduction of cephalometric radiography, there was a call for the use of a standardized, reproducible head position, such as natural head position, to facilitate accurate radiographic cephalometric orthodontic evaluation.[43–45]

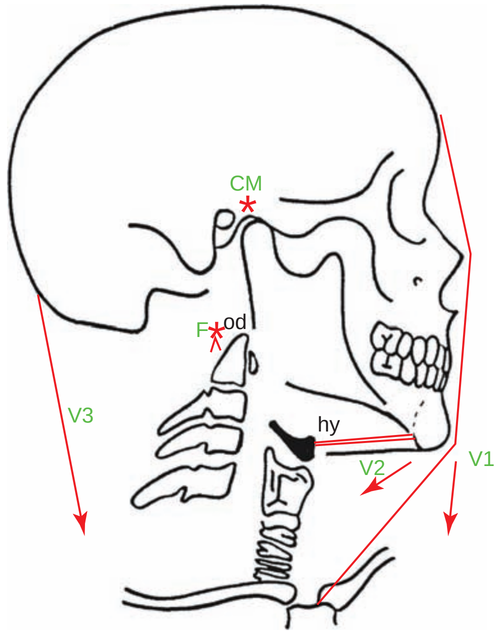

FIGURE 6-12 Some of the force vectors that are involved in stabilizing the cranium with its center of mass (CM) located some 17 to 23 mm anterior to the fulcral axis of the skull. V3 represents the posterior cervical extensor muscles of the neck; V2, the suprahyoid and inferior hyoid muscles and some of the mass of the trachea and lungs; and V1, the anterior soft tissue drape of the face, which includes the musculus platysma.

For many years, there has been an intuitive belief that the visual axis of the skull, the alignment of the cervical column, natural body posture, and natural head position are somehow closely associated and that natural head position is highly reproducible.[46–48] The concept of a natural head position, originally defined by Broca[49] as being the position of the head when an individual stands with the visual axis in the horizontal plane, was introduced to orthodontics in the 1950s.[42,50,51] The visual axis can be aligned with the horizontal plane by asking a relaxed subject to look at a distant reference point or by asking an individual to take a step forward.[42,46] While taking a step forward, an individual usually will attain a natural head position also known in this instance as the "orthoposition." To classify all of the aforementioned cranial orientations as being natural head positions is probably correct, whereas natural head posture denotes a range of normal cranial orientations that may vary to a greater or lesser degree from the natural head positions derived by a variety of means. To this end, some have attempted to record and measure natural head posture in a dynamic manner over periods of time lasting from seconds to hours.[52–54]

A recent trend for research has been to focus on the possible role of extrinsic factors that are able to affect cranial posture in a manner that could be associated with aspects of specific malocclusions.[57] In this regard, extension and flexion of the head away from the natural head position have been observed to be associated with certain morphologic patterns.[20] Although such associations have been reported in the literature, assigning definite cause-and-effect relationships to a number of well-recognized aberrant craniofacial functions and specific facial features has been difficult.

The initial optimism of Angle[58] for the concept that increased functional demands stimulated growth subsequently was replaced by the more pessimistic opinion that form was inherited, was immutable, and dictated function.[59,60] More recent studies acknowledge that growth control is likely the result of the combined influences of heredity and function.[61] This realization implies an opportunity for orthodontists to modify environmental factors in the expectation of achieving some control over final facial form, as is evidenced by the current interest in functional appliance therapy. Two major physiologic cranial functions—cranial posture and respiration—have been implicated as possible modifying factors in the control of growth and in the determination of dentofacial morphology.

Cleall[29] demonstrated that cranial extension results when the tongue is deflected by the insertion of an intraoral appliance. Cranial extension beyond the normal cranial position also occurs when full dentures are inserted in patients who are edentulous and when a transpalatal bar is inserted as part of orthodontic treatment.[62] The aforementioned appliances displace the tongue by intruding into the space of the oral cavity; in addition, the placement of full dentures tends to rotate the mandible in a clockwise (opening) direction. This finding follows the observations made by Vig et al.,[63] who noted a jaw opening movement beyond the normal average freeway space during nasal obstruction. The long-term changes in hyoid bone position and craniovertical posture in complete denture wearers were studied over a period of 15 years. In that study, the vertical changes in the hyoid position followed the patterns of change in the mandibular inclination, whereas the horizontal changes were more in tune with the changes in cervical inclination and craniocervical angulation.[64]

A functional relationship appears to exist between the temporomandibular and craniocervical regions, and head movements apparently are an integral part of natural jaw opening and closing. Functional jaw movements comprise concomitant mandibular and head-neck movements, which involve the temporomandibular, the atlanto-occipital, and the cervical spine joints, caused by jointly activating the jaw and neck muscles.[65] According to Zafar et al.,[66] jaw and neck muscle actions are elicited and synchronized by preprogrammed neural commands that are highly integrated, particularly at fast speeds. As a result of observations made during fetal yawning, the authors suggested that these motor programs are innate.

These and other studies lend credence to the concept that although the posture of the head may be related primarily to efforts expended in resisting the force of gravity, nevertheless the physiologic requirements associated with respiration, deglutition, sight, balance, and hearing also must affect cranial deportment.[20,26] Thurow[67] demonstrated that the hyoid bone is pulled forward by passive stretch of the suprahyoid muscles when the head is extended. In this respect, the midline raphe of the musculus mylohyoideus consists largely of fibrous tissue with little scope for stretching (Figure 6-13). Such cranial extension is seen commonly in mouth breathers, and this postural change could represent an important compensation for nasal airway inadequacy.[68]

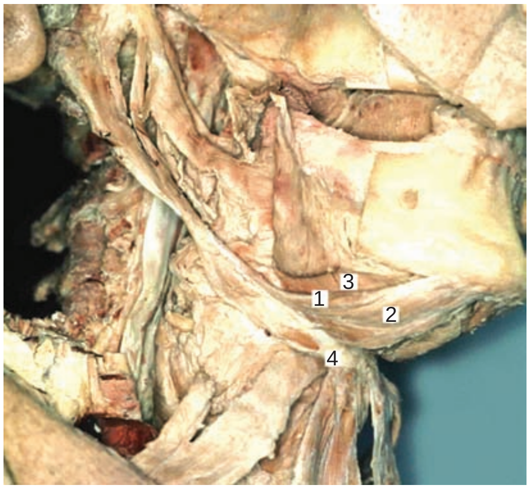

FIGURE 6-13 Prosection of the hyoid bone with its attached muscles shows (*1*) the right anterior belly of the musculus digastricus, (*2*) the right musculus geniohyoideus, (*3*) the musculus mylohyoideus, and (*4*) the hyoid bone. The superficial fibers of the stylohyoid muscle also can be discerned as they join the styloid process with the hyoid bone.

Two major groups of muscles, the suprahyoid and infrahyoid, attach to the hyoid bone. The digastric muscles increase the anteroposterior dimension of the oropharynx during deglutition, whereas the posterior belly of the digastric and the stylohyoid muscle act together to prevent regurgitation of food after swallowing.[69] The suprahyoid muscles depress the mandible by contracting against a fixed hyoid platform while they also play an active and important part in maintaining cranial balance. In turn, the suprahyoid muscles suspend the hyoid bone, the larynx, the pharynx, and the tongue. Because these muscles attach at or near the symphysis of the mandible, it follows that should the hyoid bone passively follow the movements of the chin, all of the aforementioned soft tissue structures could move to impinge on the oropharyngeal airway. The fibrous mylohyoid raphe and the stylohyoid ligament act as "rigging lines" that dictate the range of possible movements of the hyoid bone. Precise measurement of the hyoid bone by cephalometric means is difficult, but within certain limitations one can make definite conclusions concerning the normal hyoid position.[70,71] Some consensus exists that the hyoid bone moves back during cranial extension and forward

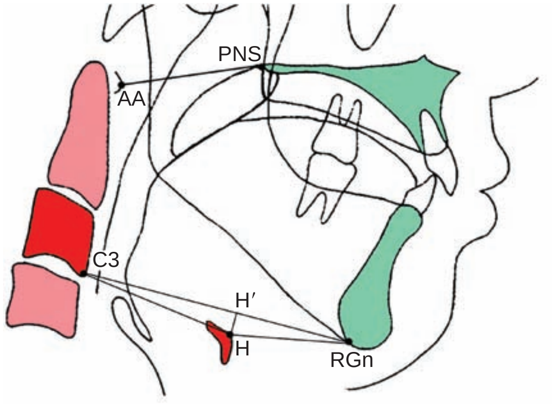

FIGURE 6-14 The triangle is formed by joining the cephalometric points retrognathion (*RGn*, the most inferior, posterior point on the mandibular symphysis), hyoidale (*H*, the most superior, anterior point on the body of the hyoid bone), and *C3* (the most inferior, anterior point on the third cervical vertebra).[75]

during cranial flexion but largely maintains its level, moving slightly backward, during mandibular opening.[72]

Hyoid Triangle

The relationship that exists between the hyoid bone, the mandible, and the cervical vertebrae is maintained from the age of 3 years, at which age the hyoid bone is located at the level of the inferior portion of the third cervical vertebra. With age the hyoid bone may descend to lie at the level of the fourth cervical vertebra.[73,74] Radiographic cephalometric studies of the hyoid bone usually use intracranial reference planes to measure the position of the hyoid bone; it is therefore not unexpected that many workers have commented that the position of this bone is variable. The hyoid triangle was developed to avoid the spurious relational effects that changes in the orientation of the cranial planes would have on measurements of the position of the hyoid bone.[75]The hyoid triangle (Figure 6-14) and analysis use planes that are located between the cervical vertebrae and the mandibular symphysis, which greatly reduces the effects that changes in cranial posture have on assessments of the position of the hyoid bone. The hyoid analysis fixes the position of the hyoid bone in three planes without the use of intracranial reference planes.

From studies of the hyoid bone, it appears that angular and vertical relationships of this bone are more variable than its horizontal location. The anteroposterior dimension of the nasopharynx—from the most anterior midline point on the arch of the Atlas vetebra to the posterior nasal spine (AA to PNS)—seems to be determined at an early age, after which this distance is relatively similar (32.9 ± 3.7 mm) for most normal adult human beings.[74,75] The linear depth of the nasopharynx compares (Table 6-1) with the distance between the body of the hyoid bone (H) and the cervical vertebrae (C3), which is also relatively constant in adults (31.8 ± 2.9 mm).

TABLE 6-1 The Hyoid Triangle

Distance*	Linear Depth of Nasopharynx†
C3-rgn	67.20 mm, SD = 6.6 mm
C3-H	31.76 mm, SD = 2.9 mm
H-rgn	36.83 mm, SD = 5.8 mm

*See Figure 6-11.
†The mean values of the hyoid triangle.[75]

Cervical Posture, Respiration, and Dental Occlusion

An association has been noted between cervical posture and dental occlusion such that children with an Angle Class II malocclusion tend to have an exaggerated kyphosis of their cervical spines compared with children who have normal occlusions.[76] This increased cervical curvature shortens the length of the neck and results in a greater cervical inclination and cranial extension than are seen in children with normal occlusions. Moderate cranial extension is thought to decrease the resistance to airflow in the upper airway passages.[77,78] Woodside and Linder-Aronson[79] postulated that mouth breathers tip their heads backward in an attempt to increase their airway, while noting that the creation of a normal airway by adenoidectomy results in a less extended posture of the head. Others have shown that the smaller the distance between the adenoids and the choanae on lateral head films, the larger is the craniovertical angle.[80] Butler[81] measured nasal resistance in normal subjects using a body plethysmograph and posterior rhinometry. He found the resistance to airflow via the nasal cavity to be more variable than the resistance of the lower airway. Hyperextension of the cranium in anesthetized subjects increases the patency of the oropharynx by separating the base of the tongue and the posterior pharyngeal wall.[82] In a study that measured upper airway resistance during complete respiratory half cycles, a cranial extension of 10 degrees from the customary head position did not significantly affect upper airway resistance.[83]Weber et al.[83] produced pure cranial extension in their subjects, whereas upper airway obstruction usually is associated with cranial extension in combination with a cervical lordosis. One can postulate that the forward inclination of the cervical spinal column is a critical aspect of attempts to improve airflow when the upper airway resistance is increased.

Experimentally, complete obstruction of the nasal airway has been associated with a 5-degree increase in craniocervical extension.[84] This extended head posture is accompanied by a change in the resting position of the mandible and subsequently in an increase in the occlusal freeway space. In a group of children who required adenoidectomy because of nasopharyngeal obstruction, Linder-Aronson[84] reported an average of a 6-degree increase in craniocervical extension. In this same sample, the craniocervical extension could not be found 1 month after surgery that was performed to remove the excess adenoidal tissue. Adenoidectomy alone may change only the breathing pattern without having a significant effect on malocclusion or facial type.[85]

In subjects with obstructed nasooropharyngeal airways, there is an associated increase in craniocervical angulation. In these subjects, the elimination of the airway obstruction is associated with a reduction in the craniocervical angulation.[86] Reduced functional adequacy of the upper airway, altered head posture, and posture-induced soft tissue stretching has been suggested as being linked in a cycle that affects cranial growth and thus facial form.[87]

Visual Stimuli and Cranial Posture

Visual stimuli are used in the central neural system to supply information about postural movements and of the relationship of an individual to the surrounding environment. Labyrinthine inputs result from angular changes in motion and thus from postural changes of the body. When a disease process disrupts labyrinthine function, the posture of the head is maintained largely by the visual righting reflexes alone. In contrast, if the visual righting reflexes are disrupted, cranial and corporal posture tend to undergo specific changes.[88,89]

Although the visual axis is thought to play a role in cranial balance, this relationship is complex and under the control of higher neural centers, including those that relate to the vestibular process. Because unsighted individuals are believed to have altered habitual cranial positions, the influence that vision has on cranial posture was studied in 20 blind subjects and 20 sighted control subjects.[90] The study found a mean of 16-degree increased cranial flexion in the blind compared with the sighted groups. Although the literature indicates that blind subjects are especially prone to anomalies in body posture, deviations in cranial posture in blind individuals have been given scant attention.[91] A study indicated that craniocervical angulation is more extended in the light than it is in the dark.[92]

MODE OF RESPIRATION AND CRANIAL MORPHOLOGY

Interpretation of the significance of variations in the growth and function of the nasal cavities, the nasopharynx, and the oropharynx depends on an understanding of the normal growth of the skull. In this respect, however, often knowledge of normal growth has been gained by the recognition and observation of abnormal cranial function and development. Thus, aberrant respiratory modes such as chronic mouth breathing have been implicated in dentofacial deformities.[59,79,93,94] In contrast, not all research workers have reported significant evidence that a relationship exists between mouth breathing and dentofacial form.[85,86] Many current concepts concerning the role of respiration in the cause of malocclusion are based on subjective impressions and anecdotal reports that form a significant part of the literature on this subject. According to the record, mouth breathing may be associated with all types of malocclusions and with normal occlusion.

The term *respiratory obstruction syndrome* has been used to describe the various morphologic traits associated with chronic obstruction of the nasal airway in growing children.[78] Other common terms for the syndrome are adenoidal facies, the long face syndrome, and vertical maxillary excess. Facial features associated with predominant mouth breathing include excessive anterior facial height, incompetent lip posture, protruding maxillary teeth, widely flared external nares, a steep mandibular plane, and posterior dental crossbite. Craniocervical posture has been related to upper airway obstruction, to craniofacial morphology, and to malocclusion. Some acceptance is given to the observation that subjects with a large mandibular plane inclination are characterized by an extended head posture and forward inclined cervical column—that is, an extended craniocervical posture.[94]

Mouth breathing may result from obstruction or restriction of any part of the upper airway. The mucous membrane that lines the nasal cavity covers the surfaces of all the cartilages and bones forming the nasal tract and extends into and lines the paranasal sinuses. Irritation of this delicate erectile tissue produces engorgement of its blood vessels, resulting in a thickening of the membrane, which in turn restricts the normal size of the nasal passages.[95] In the course of a day, individuals usually breathe in a cyclic fashion through the left, the right, or both nasal passages. This breathing cycle is controlled mostly by temporary changes in the thickness of different areas of the nasal mucosa.

The pharynx is a muscular tube that extends superoinferiorly from the base of the cranium to the level of the inferior surface of the body of the sixth cervical vertebra. The pharynx lies dorsal to the nasal cavity, the oral cavity, and the larynx. The nasal part of the nasopharynx resembles the nasal cavity in possessing a highly vascular mucosa that is rich in lymphoid tissue. The mucosa of the nasal section of the nasopharynx is of the respiratory type, whereas the posterior part resembles the oropharynx in having a stratified squamous epithelium. The nasal portion of the nasopharynx has bony elements in its wall and thus is rigid, whereas the pharyngeal portion is contractile as a result of the muscular nature of its wall.

Geometrically, the bony nasopharynx in the median sagittal plane is shaped like a gable (Figure 6-15). The anterior part of the gable is formed by a line joining the

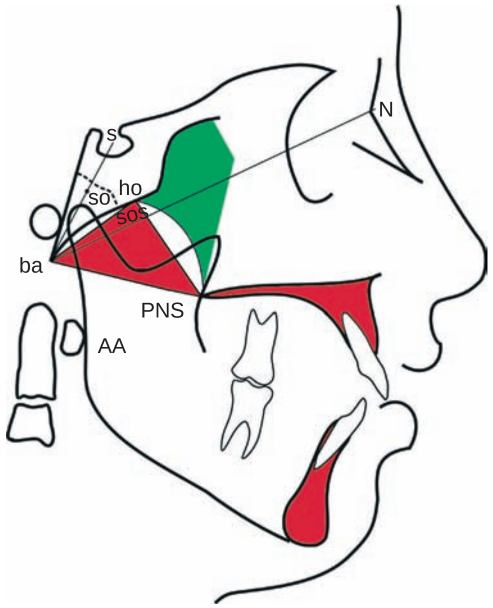

FIGURE 6-15 The cephalometric bony nasopharynx defined by the lines that join the landmarks *PNS, ho,* and *ba*.

posterior nasal spine to hormion—that is, the dorsocaudal point of contact of the vomer with the sphenoid bone. In human beings this line lies in a plane that approximates to the main direction of the pterygoid processes—the choanal plane. A line joining hormion and basion forms the posterior part of the gable. This line is used by convention, although it excludes the region between basion and AA, which contributes to the posterior wall of the nasopharynx.[96,97] The bony roof of the nasopharynx is made up of the inferior aspect of the clivus that is formed by midline portions of the sphenoid and occipital bones.

The flow of inspired air is subject to the physical constraints of fluid-flow dynamics, which deals with factors that result in resistance to the flow of gases. For practical purposes, constriction, anywhere in the upper airway, is the main cause of resistance to nasal airflow. In this respect, the liminal valve at the entrance to the nasal air passages, as well as the mucosal covering along the turbinates, may contribute substantially to the obstruction of inspired air. More posteriorly, the size of the nasopharynx may be of particular importance in determining whether the mode of breathing is predominantly nasal or oral.

Invasion of lymphoid tissue into the palatine, posterior pharyngeal, adenoid, and lingual tonsillar regions takes place during the third to fifth intrauterine months. These lymphoid masses encircle the upper part of the oropharynx to form an incomplete ring (Waldeyer ring) of immunodefensive tissue that grows postnatally to bulge into the oropharynx. The adenoidal tissue is thought to hypertrophy during the period shortly before puberty.[67,98] This enlargement of lymphoid tissue enhances the chances of the nasopharyngeal airway being constricted, and consequently the relationship between the size of the adenoids and that of the bony nasopharynx is important.

Tomes,[99] who reported that children with enlarged adenoids display V-shaped dental arches, proposed a compression theory. The narrowing of the upper arch is ascribed to a low tongue position in combination with an unbalanced compressive force on the buccal segments of the maxillary arch. Other studies focused more on the relationships that exist between modes of breathing, cranial posture, muscle tension, and those craniofacial features that are displayed on a lateral cephalometric radiographic film.[94,100] At least one study points out that all of the clinical trials of adenoidectomy tested the efficacy of these surgical procedures in children in whom the indications for this procedure were questionable.[101]

Cephalometrics of the Upper Airway

The use of lateral cephalometric radiographs to evaluate the upper airway is limited because they provide two-dimensional pictures of the nasopharynx, which consists of complex 3D anatomic structures. Not withstanding this observation, Linder-Aronson[102] found a high level of correlation between the results of posterior rhinoscopy and radiographic cephalometrics in the assessment of adenoid size. This observation was made also by previous authors who found that lateral skull radiographs provide a good picture of the size of the nasopharyngeal airway in children of all ages.[103–105] The functional adequacy of the upper airway should always be evaluated fully, making use of all of the appropriate diagnostic means.

Linder-Aronson and Henriksson[106] set out to determine the average anteroposterior size of the nasopharyngeal airway in children from 6 to 12 years of age. Their results showed that when planning orthodontic therapy, a clinical record of the mode of breathing could be supplemented with radiocephalometric data on the anteroposterior size of the nasopharyngeal airway. The standard values obtained in the study (Table 6-2) showed that an otologic examination of the nasopharyngeal space should be recommended, if certain distances were less than the mean minus 1 standard deviation, for nose breathers in the appropriate age group.

Observations on consecutive tracings of individual children show that the outline of the soft tissue and the airway varies from year to year. During development, the inferior margin of the adenoid tissue outlined against the airway is convex, and with maturity it becomes concave. Jeans et al.[107] suggest that linear measurements of the soft tissues of the nasopharynx are unreliable and that measurements of areas are more meaningful in studies of the upper airway. They also found that growth of the bony nasopharynx, in the sagittal plane, measured on lateral radiographs is mainly in height (0.8 to 1.0 mm

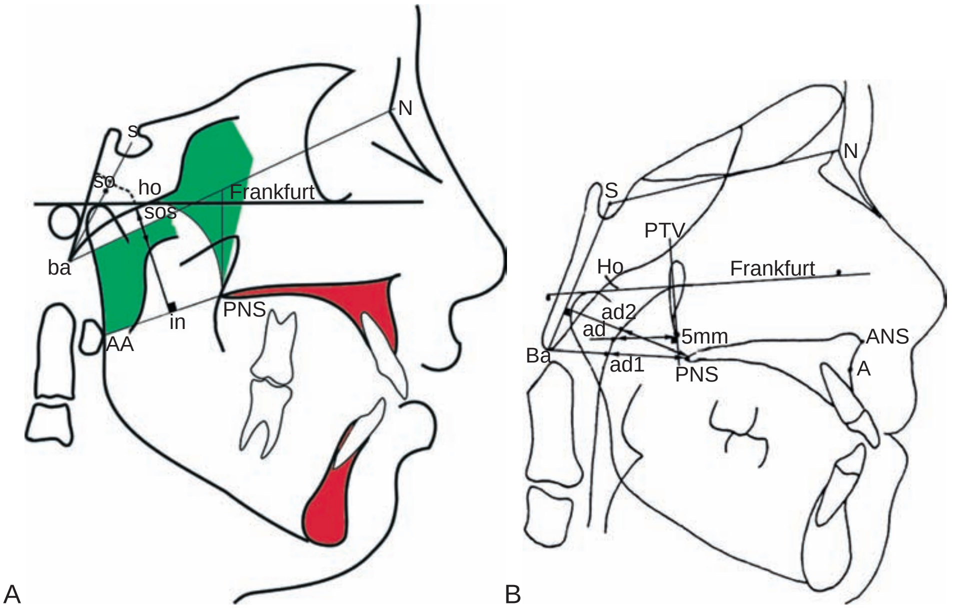

FIGURE 6-16 Four linear measurements used to determine the thickness of the adenoidal tissue. These distances are measured to the nearest adenoidal tissue along the lines *sos-in, ad, ad1,* and *ad2*.

TABLE 6-2 Percentage of Airway Area Relative to the Nasopharyngeal Area

Measure		Male		Female	
		6 Years	16 Years	6 Years	16 Years
% (so-in)	Mean	50.55	63.96	50.99	62.68
	SD	±15.85	±12.80	±13.49	±16.09
D-ad1	Mean	20.66	26.48	14.74	26.32
	SD	±5.50	±5.45	±5.69	±4.28
D-ad2	Mean	15.89	22.44	14.93	21.78
	SD	±3.53	±4.26	±3.52	±4.67
D-PTV	Mean	7.07	14.59	7.02	14.56
	SD	±3.85	±6.10	±3.87	±4.70

Mean data are from Schulhof[107] for the percentage of airway area relative to the nasopharyngeal area and three linear measurements of airway patency. The data were obtained from the Foundation for Orthodontic Research and apply to white American children. Two of the measurements used were those used by Linder-Aronson and Henriksson,[106] a third was derived from the study of Handelman and Osborne,[108] and the final dimension measured the distance to the nearest adenoid tissue from a point on the pterygoid vertical, 5 mm above the posterior nasal spine.[109] As a result of his study, Schulhof[107] suggested that surgeons could perform complete or partial adenoidectomies in selected patients.

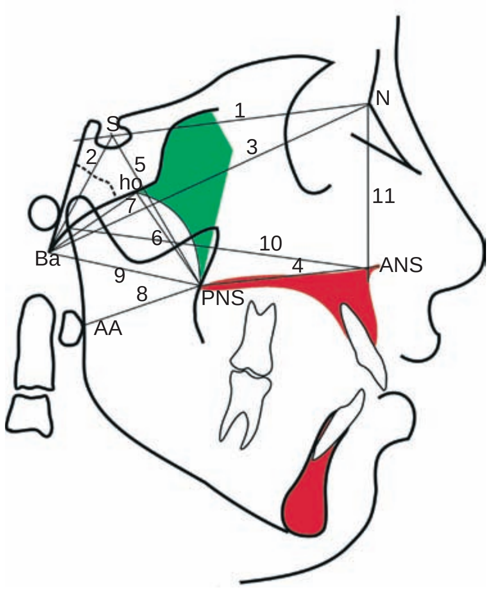

FIGURE 6-17 Some important linear measurements used in radiographic cephalometric studies of the upper airway (see Box 6-2).

per year). In boys the area of nasopharyngeal soft tissue is constant after the age of 6 years, whereas in girls this area decreases slowly from 9 to 19 years of age.

Studies dealing with the growth of the upper airway preferably should be carried out by relating the skeletal maturation of the subjects being studied to the skeletal maturation of children on whom specific maturational standards are based.[108] In a technical sense, another recommendation is that cephalometric radiographs taken to evaluate the upper airway be exposed while the subjects maintain their natural head position and preferably without the use of a cephalostat.

Definitions of some radiographic cephalometric landmarks frequently used in studies of the upper airway (Figure 6-16) are shown in Box 6-1. Some reference lines used in radiographic cephalometric studies of the upper airway (Figure 6-17) are shown in Box 6-2. Figure 6-18 and Box 6-3 show some important angular measurements used in radiographic cephalometric studies of the upper airway.

BOX 6-1 Definitions of Some Radiographic Cephalometric Landmarks Frequently Used in Studies of the Upper Airway

AA Anterior arch of the atlas; the most anterior (ventral) point on the anterior arch of the atlas (C1) assumed to be in the median sagittal plane (see Figure 6-14)

ad Intersection of the line drawn at right angles to the pterygoid vertical and 5 mm above the posterior nasal spine (PNS) and the posterior nasopharyngeal wall (see Figure 6-14)

ad1 Intersection of the line PNS-ba and the posterior nasopharyngeal wall (see Figure 6-14)

ad2 Intersection of the line PNS-so and the posterior nasopharyngeal wall (see Figure 6-14)

ba/Ba Basion; most posterior limit of the lowest point in the midline on the anterior margin of the foramen magnum (this is external basion or ectobasion) (see Figure 6-14)

C2 (cv2p[103]), C3 (cv3p[103]), C4 (cv4p[103]) Most posterior points on the inferior margins of the outlines of the bodies of the respective cervical vertebrae

C2c Anteroposterior midpoint on the inferior margin of the body of the second cervical vertebra (axis)

ho/Ho Hormion; the most posterior contact point of the vomer with the body of the sphenoid bone; assumed to lie in the midsagittal plane between the alae of the vomer. On a lateral cephalometric radiograph hormion is that point where the posterior border or choanal crest of the vomer meets the pharyngeal outline of the cranial base, and this is assumed to be in the median plane (see Figure 6-14).

hy Hyoidale; the most superior point on the anterior surface of the outline of the body of the hyoid bone; assumed to lie in the median sagittal plane of the hyoid bone

in Inferior end of the perpendicular from sos to the line that joins PNS to AA (see Figure 6-14)

od Most superior point on the tip of the odontoid process as seen on a lateral cephalometric radiograph

rgn Retrognathion; the most inferior point on the posterior surface of the symphysis of the mandible; assumed to be in the median plane

so Midpoint of the sella-basion line (see Figure 6-14)

sos Sphenooccipital synchondrosis; the most inferior point in the anteroposterior middle of the sphenooccipital synchondrosis as seen on a lateral cephalometric radiograph (see Figure 6-14)

cv2tg Most posterior point on the superior curvature of the tip of the odontoid process

BOX 6-2 Some Reference Lines Used in Radiographic Cephalometric Studies of the Upper Airway (see Figure 6-15)

Cervical axis Line od-C5c

Odontoid tangent Line that passes through cv2p and is tangent to the posterior surface of the outline of the odontoid process

Pterygoid vertical (PTV) Line that passes through the pterygomaxillary fissure and is perpendicular to the Frankfurt plane

The following are some important linear measurements used in radiographic cephalometric studies of the upper airway:

1. Length of the (presellar) anterior cranial base (S-N), where S is the position of the pituitary fossa and N is the nasion
2. Length of the postsellar part of the posterior cranial base (ba-S)
3. Total or effective cranial base length (ba-N)
4. Length of the palate (floor of the nasal cavity)
5. Posterior height of the nasal cavity (S-PNS)
6. Vertical diameter of the choanal openings (ho and PNS)
7. Length of the pharyngeal clivus (ba to ho)
8. Length of the floor of the nasopharynx (AA to PNS)
9. Total depth of the nasopharynx
10. Effective length of the maxilla (TMJ to ANS, where TMJ is the temporomandibular joint and ANS is the anterior nasal spine)
11. Upper anterior facial height (N and ANS)
12. Distance from so to in
13. Distance from AA to hy
14. Distance from hy to rgn

BOX 6-3 Some Important Angular Measurements Used in Radiographic Cephalometric Studies of the Upper Airway (see Figure 6-16)

1. Saddle angle included between the lines joining ba to S and S to N (ba-S-N)
2. Angle between the anterior cranial base and point "A" on the maxilla
3. Angle between the palatal plane (PNS-ANS) and the anterior cranial base (S-N)
4. Angle of nasopharyngeal depth and the included angle ba-S-PNS
5. Vertical angle of the nasopharynx and the included angle PNS-ba-S
6. Roof angle of the nasopharynx and the included angle ba-ho-PNS
7. Craniocervical angle included between the superior extension of the tangent to the posterior surface of the odontoid process and the posterior extension of the line ba-S

Figure 6-19 shows some area measurements used in radiographic cephalometric studies of the upper airway. The area of the bony nasopharynx frequently is defined as a trapezoid demarcated by the following lines: AA-PNS; the pterygoid vertical between PNS and the intersection of this vertical line and line ba-N; a line drawn through AA, parallel to the pterygoid vertical and extended to intersect line ba-N; and the section of line ba-N between the pterygoid vertical and the vertical erected through point AA. The area of the adenoid tissue, seen on a sagittal cephalometric radiograph, can be expressed as a percentage of the area of the nasopharynx. Despite the considerable attention given to the growth of the pharynx, the statement of Scott[109] that "less is known about the growth of the pharyngeal region than any other part of the face" is still largely true.

Growth of the Nasopharynx

Although general agreement exists that in growing children the height and width of the nasopharynx depend closely on age,[67] some difference of opinion exists as to the relationship between age and the sagittal depth of the nasal part of the pharynx. An early viewpoint held that the size of the nasopharynx increases along with the growth of the posterior cranial base.[110] More recently, researchers concluded that the depth of the nasopharynx is established during the first 2 years of life and that thereafter this dimension remains constant, the concept being that growth at the sphenooccipital synchondrosis is offset by forward growth of the anterior arch of the atlas and posterior growth at the posterior nasal spine so that the increase in depth of the bony nasopharynx is kept to a minimum.[73,111]

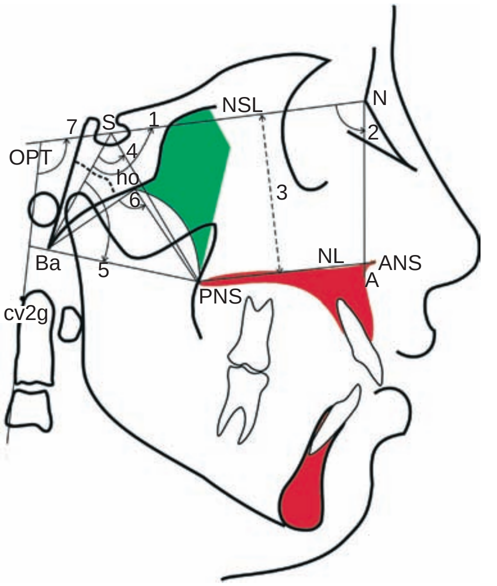

FIGURE 6-18 Some important angular measurements used in radiographic cephalometric studies of the upper airway (see Box 6-3).

From the available studies dealing with growth of the nasopharynx, it appears that the data should be ranked according to skeletal rather than chronologic age. Pubertal growth spurts, as well as sexual dimorphism in the growth patterns, are more obvious when the data are ranked according to biologic landmarks.[108]

Allergy, Respiration, and Facial Growth

Heredity plays an important role in determining the size and shape of the human face and thus of the airway; however, environment appears to play a major part in the cause of nasal obstruction. Marks[112] states that the sensitization of nasal mucous membranes may propel allergic infants toward progressively severe allergic manifestations, one of which may be dentofacial deformity. Preliterate peoples are said to be comparatively free from allergic diseases. Balyeat and Bowen (cited in Ricketts[78]) remarked on the paucity of allergic manifestations and dentofacial abnormalities in preliterate peoples such as the Oklahoma Indians, whereas Sincock (cited in Ricketts[78]) stated that he had never seen Chippewa Indians with hay fever, asthma, or eczema. These authors attributed their findings largely to the fact that Native American babies were breastfed for fully 9 months or longer without supplemental foods or water. Accordingly, when early feeding of cow's milk and adult foods was introduced, eczema and other allergic manifestations appeared.

Some early and subsequent studies dealing with children with respiratory obstruction syndrome conclude that these children were slow learners at school.[57] Allergic disease significantly affects the quality of life and, particularly if it is untreated, may affect adversely the ability of children to function adequately at school. In children with learning disabilities, the impact of allergies

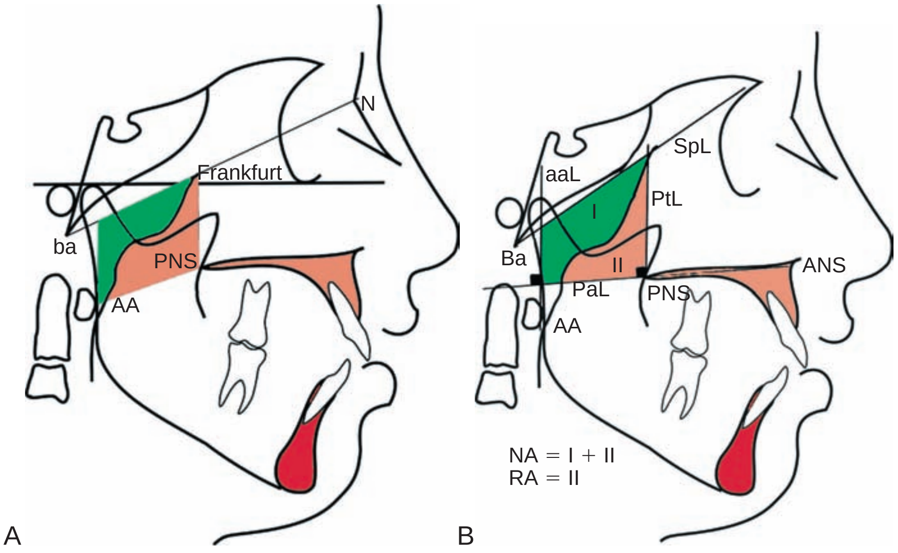

FIGURE 6-19 Two techniques have been used to measure the adenoid **(A)** and the respiratory **(B)** areas.

may be greater.[113] Poor sleep, headaches, and fatigue resulting from untreated chronic rhinitis and school absenteeism in asthmatics can greatly affect children's school performance. Children with learning disabilities and hyperactivity have difficulty functioning in mainstream schools and frequently require remedial teaching or education in special schools. If these children have untreated allergies, their ability to function at school is likely to be impaired further. The prevalence of allergies in westernized populations has increased rapidly during the past 20 years, and allergies tend to be more common in city-dwelling children compared with the rates observed in their rural counterparts.[114] Allergies, learning disabilities, and hyperactivity have a direct and adverse effect on orthodontic treatment and on patient compliance.

The treatment options for a patient who has a malocclusion associated with nasal obstruction, enlarged adenoids, and allergies require a team approach for appropriate care. Referral to an otolaryngologist for surgical intervention may not be sufficient. Removal of inciting allergens also should be considered with a referral to an allergist. Optimally, the mode of respiration should be assessed as early as 2 years of age, and the appropriate medical management of any detected problems should be instituted. Pharmacologic treatment is the mainstay of treatment in an attempt to mitigate against the inflammatory reaction. This treatment will take the following form:

- Immunotherapy in an attempt to reduce the response of the body to specific allergens
- Antiinflammatory medication to interrupt the inflammatory cascade (including antihistamines, steroid therapy, and leukotriene inhibitors)
- Bronchodilators
- Antibiotic therapy to control superimposed infectious processes
- Surgical evaluation for removal of infected adenoids and enlarged tonsillar tissue

Not uncommonly, orthodontic patients have bronchial asthma, which is a chronic disorder characterized by smooth muscle dysfunction, airway inflammation, and airway remodeling. The incidence of asthma in North American children may be as high as 16.5%, whereas wheezing, a symptom of asthma, has been reported by 24.2% of American children in the 13- to 14-year age group.[115] Potential explanations for differences in the incidence and severity of asthma include family history of atopic conditions, early life events such as breastfeeding and childhood infections, diet, lifestyle, and indoor and outdoor pollution. Orthodontists also should be aware of exercise-induced bronchospasm, which is defined as a condition in which vigorous physical activity triggers acute airway narrowing in individuals with increased airway responsiveness. The prevalence of exercise-induced bronchospasm in asthmatic individuals varies from 40% to 90%.[116]

The rising incidence of allergic disorders, particularly in Western societies, has generated substantial research into the underlying reasons that may contribute to this trend. As the increase of allergic disorders has occurred over a short period of time, a genetic cause alone seems unlikely. Two general hypotheses have been proposed in an attempt to explain this well-documented trend:

1. New risk factors that were unknown several decades ago have become relevant in connection with nutrition, environmental exposure, or lifestyle.
2. Protective factors that were related to a more traditional lifestyle in the past have been lost, which have led to a greater susceptibility to atopic disease.

Manipulation of the intestinal flora through the use of prebiotics and probiotics has been suggested as a therapeutic modality that addresses two candidate environmental factors thought to contribute to the increase in allergic diseases: hygiene and nutrition.[117] Controlling the allergy epidemic may be accomplished in part by providing safe and nutritionally well-characterized live microorganisms (probiotics), with the potential to improve the gut mucosal defense barrier and to serve as a microbial stimulus for the human immune system.

Inhaled corticosteroids have become the cornerstone of treatment of persistent asthma in children, but uncertainty exists regarding various aspects of their use, including safety concerns. Inhaled corticosteroids should be used in children who have symptoms of persistent asthma, irrespective of age. The safe dose of inhaled corticosteroids is regarded as 400 mg/day of budesonide equivalent; side effects are associated with increasing doses. Current evidence suggests that this dose is safe in long-term growth studies in children with asthma but that growth monitoring should take place at regular intervals. Adding other controllers to inhaled corticosteroids should be considered preferable to increasing doses to greater than 400 mg/day of budesonide equivalent.

Obstructive Sleep Apnea

Just as allergic disease significantly affects quality of life, obstructive sleep apnea, if it is untreated, may affect adversely the ability of adults and children to function adequately at work and at school.

The question is raised, Is obstructive sleep apnea an anatomic disorder?[118] Those who support the anatomic viewpoint state that no real debate exists, for patients with sleep apnea almost invariably are obese or have abnormal upper airway anatomy retrognathia, tonsillar hypertrophy, macroglosia, enlargement of the peritonsillar folds, or enlargement/elongation of the soft palate. Obesity increases the size of the soft tissue structures in the upper airway, which decreases the functional size of the upper airway, which in turn predisposes to sleep apnea. Obstructive sleep apnea is a state-dependent condition occurring only during sleep. Schwab[118] suggests that sleep apnea is the anatomic compromise that allows the reduction in motor activity of airway dilator muscles that occurs during sleep to have such profound effects. Furthermore, because the risk factors are structural and the treatment options for sleep disordered breathing area based on enlarging the upper airway, it seems clear that obstructive sleep apnea could be an anatomic disorder. All the therapeutic options for the treatment of obstructive sleep apnea (continuous positive airway pressure, weight loss, oral appliances, and upper airway surgery) increase upper airway caliber by altering upper airway anatomy.

That neck circumference is a strong predictor of sleep-disordered breathing indicates that upper body obesity, rather than more generalized distribution of body fat, is important for the development of sleep apnea. Moreover, nonobese subjects developing sleep apnea have larger parapharyngeal fat pads than do normal subjects. Studies using 3D magnetic resonance imaging analysis techniques have confirmed that the volume of the upper airway soft tissue structures are enlarged in patients with sleep apnea and that this enlargement is a significant risk factor for sleep apnea. In addition to changes in upper airway soft tissue structures, alterations in craniofacial structures have been shown to predispose patients to obstructive sleep apnea. Numerous studies using cephalometrics have demonstrated craniofacial abnormalities in patients with obstructive sleep apnea, compared with age- and gender-matched control subjects.[118] These studies in general have demonstrated that patients with sleep apnea have a small retroposed mandible, narrow posterior airway space, enlarged tongue and soft palate, inferiorly positioned hyoid bone, and retroposition of the maxilla. These craniofacial risk factors have been reported to have their strongest association with sleep apnea in nonobese patients. Data from previous studies indicate that elements of craniofacial structures in sleep apnea are inherited.

The most fundamental argument for neural events as initiating obstructive sleep apnea is the fact that closure of the pharyngeal airway occurs during sleep. A reorganization of neural control in sleep has been noted that includes changes in direct cortical drive to and peripheral reflex control of the muscles of the chest wall and upper airway and ventilation. The disease-defining event is state related, requiring sleep in the presentation of the disease obstructive sleep apnea–hypopnea syndrome.[119] According to Strohl,[119] the presence of an anatomic encroachment of the upper airway by itself does not produce an obstruction. Apparent anatomic predispositions require greater levels of upper airway muscle activity to maintain an open airway during wakefulness. With sleep onset, however, this neural compensation is reduced, thus producing the fundamental cause. According to this viewpoint, the focus should be on optimizing the neural drive to muscles that maintain the patency of the upper airway during sleep and preventing the next apnea through stabilization of respiratory control.

Tomography of the Upper Airway

Some clinicians believe that to evaluate the patency of the upper airway from lateral or, for that matter, frontal cephalometric radiographs as discussed by Ricketts and Grummons[120] is impossible. Their point of view is that this process would be similar to guessing what is in a tunnel by looking at its entrance. Although studying the upper airway with volumetric radiographs is preferable, cephalometric radiographs can provide valuable information regarding nasopharyngeal pathology.

The problems associated with an x-ray cephalometric study of the upper airway can be divided roughly into two groups. In the first group are those problems that result from difficulties encountered in landmark identification. A second group of problems results from the fact that conventional x-ray films yield two-dimensional pictures of 3D structures. Certainly, the problem associated with estimating the 3D size of adenoidal tissue from a cephalometric radiograph, which essentially provides information in two planes, remains a real one[87] (Figure 6-20). Vig[87] made an eloquent appeal for researchers to base claims that link predominant respiratory mode and facial form on sound evidence-based research.

In recent years, a number of manufacturers have produced x-ray equipment that specifically produces

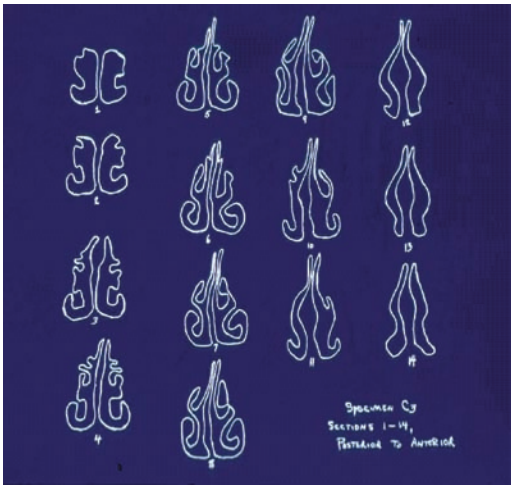

FIGURE 6-20 Tracings of a series of 14 coronal computerized axial tomography scan sections of the bony nasal air passages. These drawings were presented by Vig[86] to illustrate how difficult it is to judge the patency of the upper airway from single plane radiographs. (Redrawn from Vig PS: Respiratory mode and morphological types: some thoughts and preliminary conclusions. In McNamara JA: *Naso-respiratory function and craniofacial growth. Monograph No 9, Craniofacial Growth Series*, Am Arbor, 1979, University of Michigan, Center for Human Growth and Development.)

volumetric radiographs of the craniofacial structures. During tomography, a DICOM (digital communication) data file of coordinates located in three dimensions on the x, y, and z axes of the skull being radiographed is created. These coordinates represent the respective anatomic points located in the craniofacial skeleton. The coordinates are recorded and stored according to their darkness on a continuous white-to-black scale that, just as in a regular x-ray film, reflects the radiopacity of the tissue point being imaged. The DICOM data files are manipulated with separate computer software capable of producing an almost endless variety of radiographs that give a 3D insight into craniofacial structures (Figures 6-21 to 6-23). Volumetric radiographs were used to compare upper airway volume and area in a pilot study of 11 normal adolescent children.[121] The findings of the pilot study show that more variability exists in airway volume than in airway area. This observation strengthens the viewpoint of Vig[87] that single-plane cephalometric radiographs do not reflect the airway volume in a reliable manner.

Volumetric imaging may be of some use when planning surgical intervention to improve the patency of the upper airway. Obstruction can occur anywhere along the upper airway, and frequently the obstruction is evident in more than one of its anatomic locations. From the outset one should note that surgical intervention should be considered only when the obstruction of the upper airway cannot be alleviated by conservative means. The cause of nasal obstruction in children usually can be identified by taking a thorough medical history accompanied by an appropriate physical examination. The physical examination should include direct observation, anterior rhinoscopy, rhinometry, and fiberoptic nasopharyngoscopy. The most common reasons for nasal obstruction are adenoid hypertrophy, nasal septal deformity, and allergic and nonallergic rhinitis.

Surgery and the Upper Airway

The most common surgical treatment for nasopharyngeal obstruction in children is adenoidectomy with or

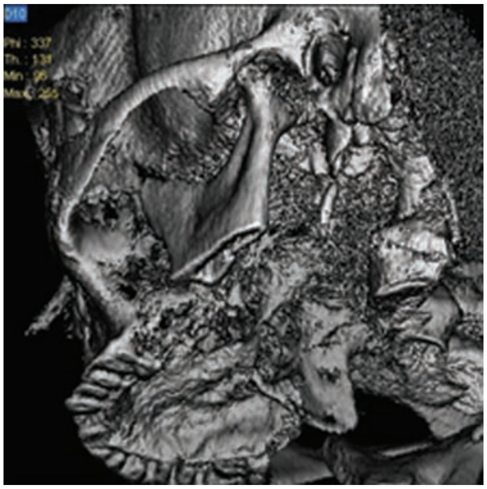

FIGURE 6-21 A NewTom-generated image of the palate and a portion of the nasopharynx of a patient.

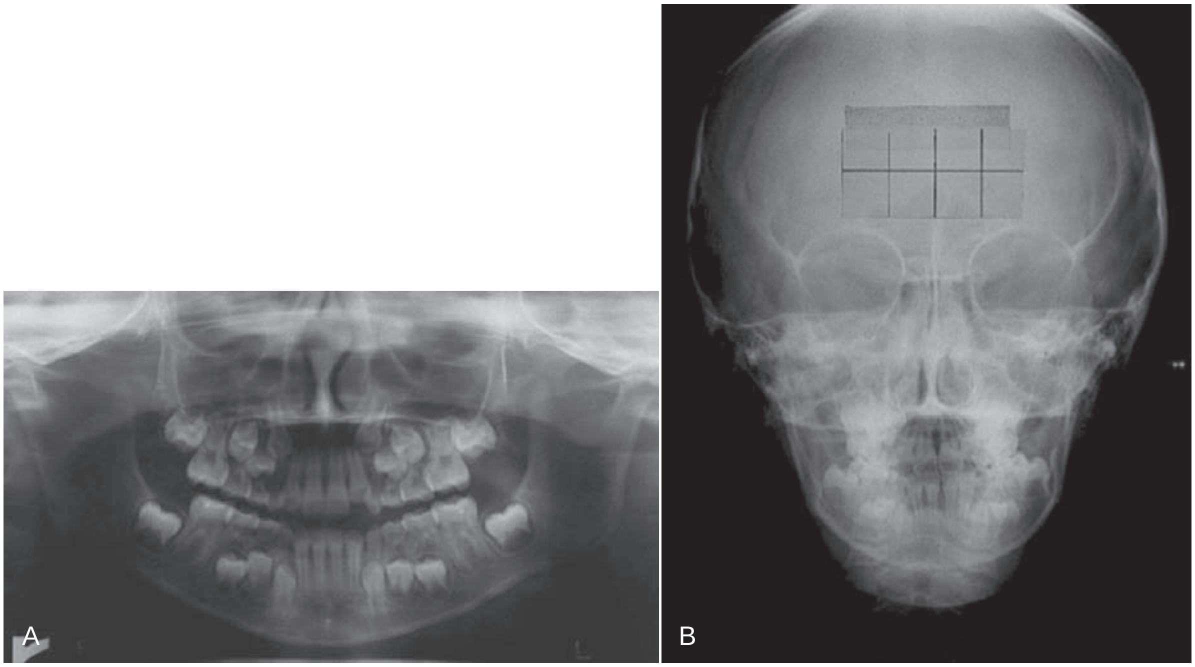

FIGURE 6-22 NewTom-generated panoramic **(A)** and posteroanterior **(B)** images of a patient with chronic oral breathing. Both of these images indicate that the patient has a deviated nasal septum and an enlarged left inferior turbinate.

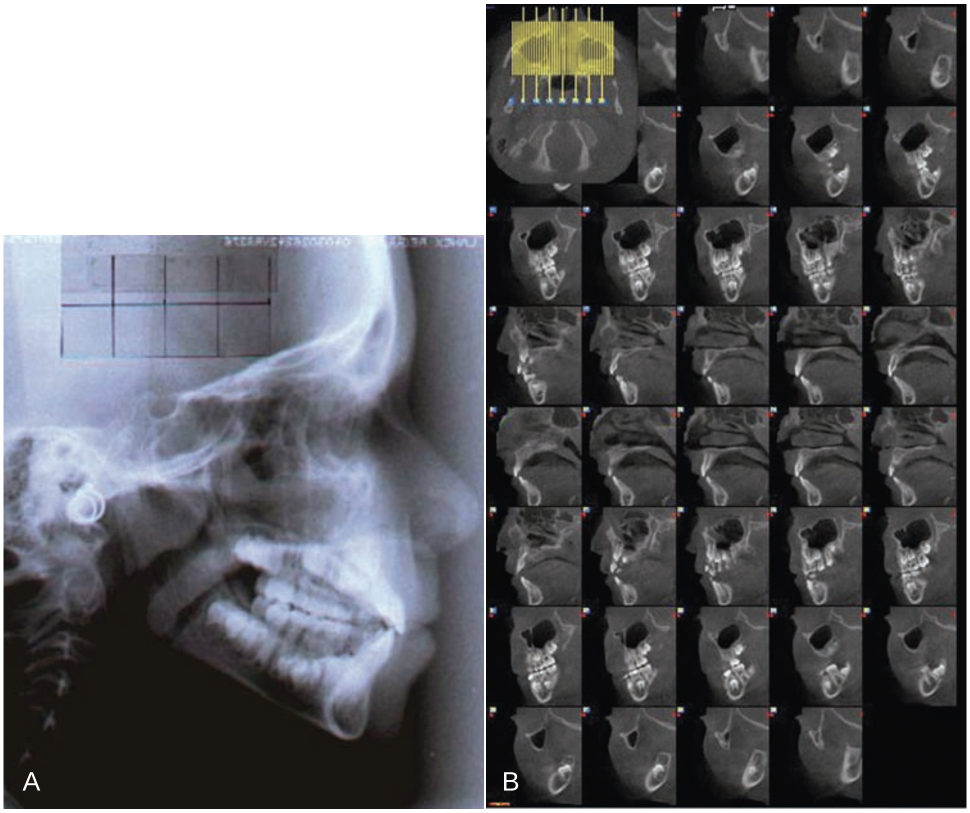

FIGURE 6-23 NewTom-generated midsagittal plane lateral cephalometric image **(A)** and images of 3-mm-thick sagittal plane slices of the face of the same patient shown in Figure 6-22 **(B).** The latter slices provide anatomic data that give a good insight into the patency of the nasal airway and nasopharynx of this patient. Images of slices in other cranial planes can be provided with little effort other than software manipulation of the original NewTom-generated data file.

without tonsillectomy. Tonsils and adenoids are present at birth and grow until the age of 5 to 7 years. When hypertrophied, however, they become symptomatic at the age of 18 to 24 months. The most common symptoms of adenoid hypertrophy are those of upper airway obstruction, which include snoring, chronic mouth breathing, and disordered sleeping. Obstructive sleep apnea is a severe sleeping disorder that can result from the chronic airway obstruction caused by enlarged adenoids and tonsils. Children with, or even those without, enlarged adenoids and tonsils frequently develop airway infections that will manifest as recurrent or chronic sore throats, chronic sinusitis, and recurrent or persistent middle ear effusion.

The indications for adenoidectomy have evolved from the early 1900s when tonsillectomy and adenoidectomy were prescribed for children routinely and almost universally. Currently, these surgical procedures are less frequently performed and then only when the following applies:

- Hypertrophy of the adenoidal tissue results in nasal obstruction.
- Recurrent or persistent otitis media is present in children in the age range of 3 to 4 years.
- Recurrent or chronic sinusitis is present.

The only absolute contraindication to adenoidectomy is found in situations in which general anesthesia cannot be used. Relative contraindications include the following:

1. Presence of a severe bleeding disorder
2. High risk of velopharyngeal insufficiency such as occurs with the following:
    a. Short palate
    b. Submucous cleft of the palate
    c. Cleft palate
    d. Generalized muscular hypotonia and the presence of an atlantoaxial joint laxity such as in Down syndrome patients

Tonsillectomy on its own or with adenoidectomy remains one of the, if not the, most common surgical procedure performed in America. Currently, several transoral techniques are used to remove adenoids. The most common technique and the one with the longest history is curettage, whereas adenoid punches and forceps also are used frequently during adenoidectomy.

Tonsillectomy is performed most commonly when attempts at conservative treatment fail to cure chronic tonsillitis. Tonsillectomy is performed increasingly for patients who have a relative upper airway obstruction, and then it is usually performed with an adenoidectomy. The procedure usually is performed transorally in an outpatient setting and under general anesthesia. Electrocautery forms the basis for the most common technique currently used to remove the tonsils. The so-called cold techniques of traditional surgery also are used to remove tonsillar tissues, but they are associated with a higher intraoperative blood loss. Newer techniques, which include the use of lasers, bipolar cautery, harmonic scalpels, and others, are available to remove the tonsils but they are not widely used. Bleeding, which usually manifests 1 week to 10 days after the tonsillectomy procedure, occurs in about 2% of the patients and represents its main postoperative complication.

The bony nasal passages form part of a complex anatomic region where upper airway obstruction most commonly occurs as a result of a deviated nasal septum. The nasal septum, which is composed of cartilage and bone, is covered by mucosa and divides the nasal cavity into right and left nasal passages. The treatment for a deviated nasal septum is based on the severity of the problem, but surgical treatment—septoplasty—remains the treatment of choice for a moderately to severely deviated nasal septum. Septoplasty is acceptable in adults and adolescents who have reached the end of their facial growth experience, as can be determined by superimposing sequential lateral cephalometric radiographs taken 6 months apart. In growing children, septoplasty represents a controversial subject, and this procedure should be performed only after careful consideration in patients who have residual facial growth. Although septal cartilage has been shown to play a role in the growth of the midface of fetuses, how much it affects postnatal facial growth is unclear. Most commonly, septoplasty is performed on an outpatient basis and then usually under general or local anesthesia with sedation. The deviated portion of the septum is removed or reshaped and replaced, but the nasal mucosa is left intact except for an anterior incision. One must take care to leave caudal and dorsal struts of at least 1-cm width to prevent secondary collapse of the nose from a lack of cartilaginous support. The main risks of this procedure are a recurrence or persistence of the deviation, bleeding, septal hematomas, infection, and, perhaps most troublesome, development of a septal perforation.

Hypertrophy of the inferior turbinate bones and their associated erectile soft tissues presents another source of nasal obstruction. The nasal turbinates, which help to humidify, filter, and warm the inspired air, are small bones that are covered by mucosa and that extend into the nasal airways. Although mucosal hypertrophy occurs most commonly, hypertrophy of the inferior turbinates can be due to mucosal hypertrophy, bony hypertrophy, or both. The mucosa covering the turbinates, in keeping with the rest of the nasal mucosa, is erectile in the sense that the thickness of these tissues varies in a cyclic fashion throughout a normal day. This cyclic variation is under the control of the sympathetic and parasympathetic nervous systems. Overactivity of the parasympathetic or underactivity of the sympathetic nervous system causes engorgement of the erectile tissues of the nasal air passages and, consequently, obstruction of the nasal airway. The engorgement of the nasal blood vessels and the resultant thickening of the associated mucosa is termed *rhinitis*, which can be allergic or nonallergic. The primary treatment for rhinitis consists of an evaluation of responses to the most common allergens. Nonallergic rhinitis presents a more vexing medical problem, and its treatment is frequently and at best unpredictable.

With allergic or nonallergic rhinitis, if symptoms become chronic, the need for surgical intervention often is indicated. Patients with allergic rhinitis who opt for nasal surgery to correct their nasal obstruction must be made aware that their symptoms are highly likely to recur after a period during which they may be relatively symptom free. The reason for this recurrence of the symptoms is that surgery addresses the symptoms caused by the allergy but not the root cause of the problem—the allergy.

The surgical treatment modalities that may be used to treat hypertrophic nasal turbinates include radiofrequency ablation of the mucosa, electrocautery of the mucosa, infracturing of the turbinates, and turbinate resection. The risks of these surgical procedures include bleeding, chronic dryness of the nasal passages, and crusting of the nose. Under these circumstances, the respective patient essentially may become a nasal cripple with constant crusting, dryness, and nasal pain. Bony hypertrophy of the nasal turbinates is treated with surgery. The most common surgical procedures involve a submucous resection of an appropriate portion of the affected turbinate bone or an outfracturing of the bone so that the turbinate lies more closely to the lateral nasal wall.

SUMMARY

The evolution of an upright posture and bipedal walking has been associated with notable changes that characterize many human bones and muscles. In the center of the most noteworthy anatomic changes that accompanied the development of a bipedal stance is the cranial base. Understanding the complexities of cranial base development, function, and architecture is important for testing hypotheses about many aspects of craniofacial variation and evolution. New diagnostic techniques that are based on 3D cephalometric analyses may hold the key to the early diagnosis and treatment of facial abnormalities that include a variety of skeletal and dental malocclusions.

The posture of the head is influenced primarily by the force of gravity, but the physiologic demands of respiration, sight, balance, and hearing also must affect cranial deportment. Several investigators have changed head posture experimentally by altering, for example, nasal airflow, mandibular position, or tongue posture and deglutition. A trend for research has been to focus on the possible role of extrinsic factors that are able to affect cranial posture in a manner that could be associated with aspects of specific malocclusions. In this regard, extension and flexion of the head away from the natural head position have been observed to be associated with certain morphologic patterns. In contrast, not all research workers have reported significant evidence that a relationship exists between mouth breathing and dentofacial form.

Function and physiology are recognized as being linked by a close anatomic and physiologic relationship that exists between the nose and lungs. Unfortunately, because most orthodontists do not possess the essential elementary instrumentation required to perform a basic nasal examination, they remain nasal neophytes. Consequently, their patients frequently suffer as a result of orthodontists failing to diagnose even the most basic nasal pathologies.

The use of lateral cephalometric radiographs to evaluate the upper airway is limited because they provide two-dimensional pictures of the nasopharynx, which consists of complex 3D anatomic structures. Notwithstanding this observation, a high level of correlation has been found between the results of posterior rhinoscopy and radiographic cephalometrics in the assessment of adenoid size. This chapter defines the most important cephalometric measurements that have been used to determine the patency of the upper airway. Also, one example is given of volumetric radiographic techniques that promise to further elucidate aspects of the normal and the abnormal functions of the upper airway.

Some research shows that the size of the nasopharynx increases along with the growth of the cranial base. In contrast, others believe that the depth of the nasopharynx is established during the first year or two of life and that thereafter this dimension remains constant. Chronologic age usually is used to rank the metric data of the upper airway, and this fact could form the basis for some of the confusion that exists in dealing with growth of the upper airway. The present review of the upper airway highlights the importance of studying this aspect of human growth according to biologic age.

The term *inflammatory airway disease* is not used often in the literature, although it now is accepted universally that some important allergic diseases of the respiratory tract—that is, asthma and allergic rhinitis—are inflammatory. The process of inflammation in these conditions is almost identical in the lower and upper respiratory tracts, and although the pathophysiologic process is well described for an allergen trigger mechanism, allergy is not the universal causative factor for all patients. The principal pathologic features of allergic rhinitis are mucosal swelling and production of abnormal copious amounts of mucus. The defining features are a blocked nose, rhinorrhea, sneezing, and itching, especially in children. There are good indications that orthodontists may have to expand the concept of the cranial functional matrix to include the pathophysiology of allergic rhinitis and asthma.

Obstructive sleep apnea can present serious health risks, and a physician, using a sleep study, must diagnose it. The final section of this chapter deals with different aspects of obstructive sleep apnea. The first of the three reviews looks at the treatment possibilities offered by appliances that are within the domain of orthodontists. Indeed, orthodontists seem to be positioned ideally to provide treatment for a large percentage of patients who have less threatening forms of obstructive sleep apnea. Despite the considerable attention given to the growth of the pharynx, the statement of Scott[112] that "less is known about the growth of the pharyngeal region than any other part of the face" is still largely true.

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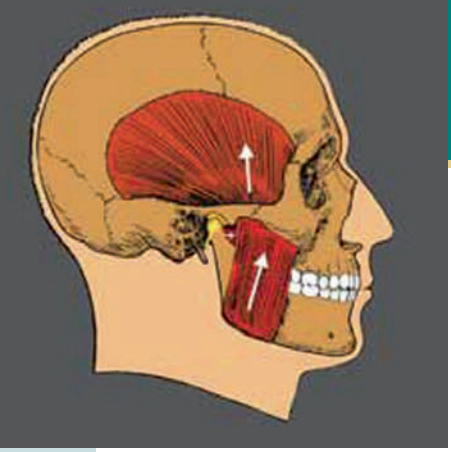

CHAPTER

7

Orthodontic Therapy and the Temporomandibular Disorder Patient

Jeffrey P. Okeson, Kazumi Ikeda

OUTLINE

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Finding the Musculoskeletally Stable Position
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INTRODUCTION

The orthodontist is constantly being challenged with the task of providing each patient with acceptable esthetics and masticatory function. Although esthetics is often the patient's immediate and primary goal, function becomes far more important over the lifetime of the patient. Developing a sound functional masticatory system needs to be the primary goal of all orthodontic therapy. No other dental specialist routinely alters the patient's occlusal condition as a part of the therapy. The orthodontist is in a unique position to either improve or worsen the occlusal condition while carrying out the esthetic goals of the therapy. It therefore behooves orthodontists to be knowledgeable of normal masticatory function and the goals that need to be achieved to maintain normal function. These goals should be met in all patients, both those with and without masticatory dysfunction.

This chapter will first discuss the principles of normal orthopedic stability in the masticatory system and define treatment goals that will help ensure normal masticatory function. Next, concepts of how orthopedic instability may relate to temporomandibular disorders (TMDs) and when orthodontic therapy may influence TMD symptoms will be reviewed. A brief TMD history and examination will be presented so that important symptoms will be identified before orthodontic therapy is begun. Next, this chapter will provide some clinical considerations regarding the management of TMD symptoms that may arise during the orthodontic therapy. Last, this chapter will end with a case presentation that will illustrate how orthodontic therapy can be incorporated into the management of a patient with a TMD.

THE CONCEPT OF ORTHOPEDIC STABILITY

For many years, the dental profession has debated the relationship between occlusion and TMDs. We have often concentrated on the precise contact pattern of the teeth and perhaps overlooked the more significant aspect of orthopedic stability. If occlusion is important to masticatory function, it must relate to how the occlusal contact pattern of the teeth relate to orthopedic stability of the entire masticatory system. In other words, the clinician needs to better understand sound orthopedic principles to more completely appreciate the importance of occlusion and its role in function or dysfunction of the masticatory system.

In establishing the criteria for the optimum orthopedically stable joint position, the anatomic structures of

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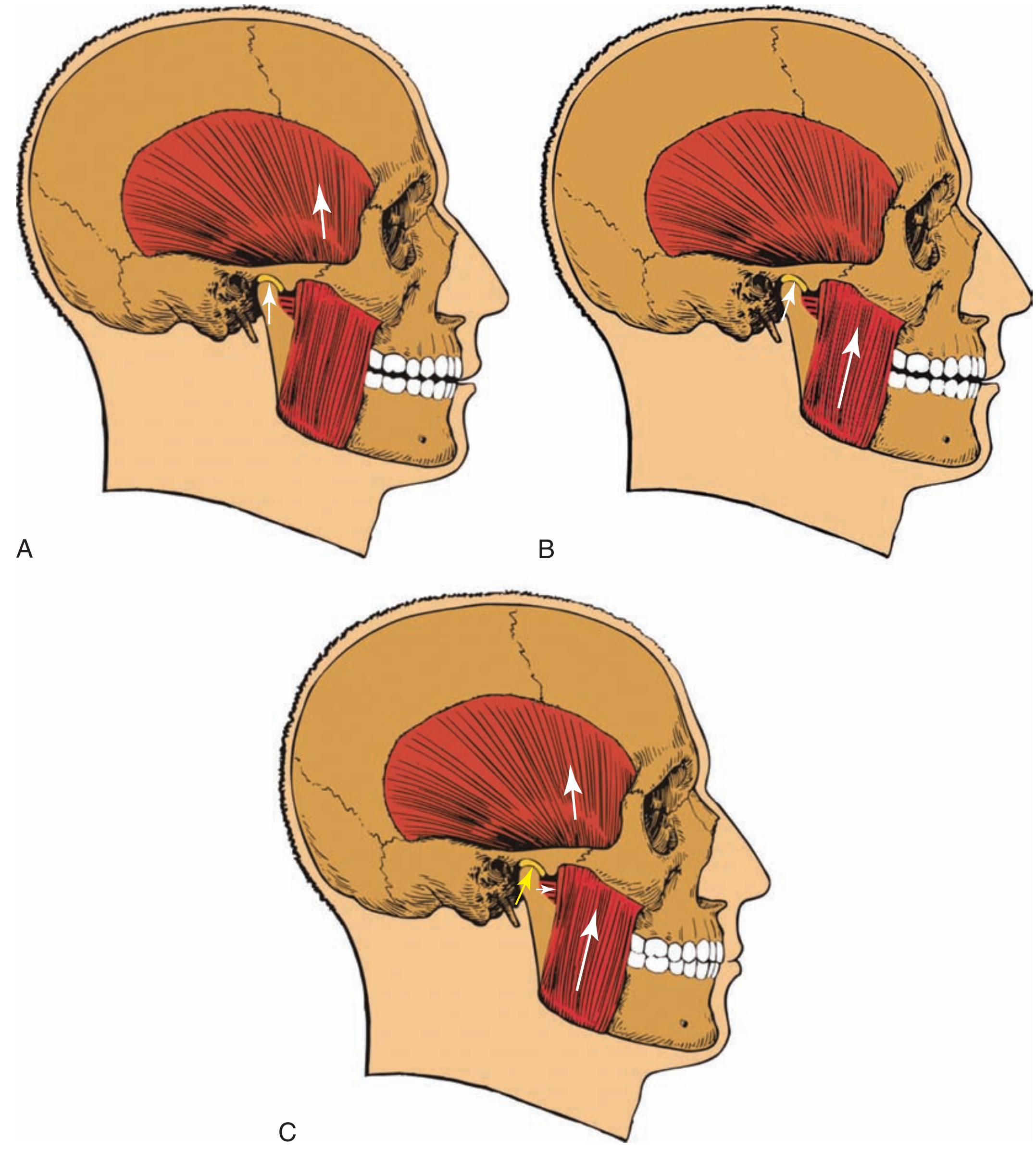

FIGURE 7-1 **A,** The directional forces applied to the condyles by the temporal muscles are to seat the condyles in a superior position in the fossae (*white arrow*). **B,** The directional forces applied to the condyles by the masseter and medial pterygoid muscles are to seat the condyles in a superior anterior position in the fossae (*white arrow*). **C,** When these forces are combined with the lateral pterygoid muscle (*small white arrow*), the condyles are seated into their superior anterior position in the fossae (*yellow arrow*).

the temporomandibular joint (TMJ) must be closely examined. The TMJ is made up of the condyle resting within the articular fossa with the articular disc interposed. The articular disc is composed of dense fibrous connective tissue devoid of nerves and blood vessels.[1] This allows it to withstand heavy forces without damage or creating a painful stimulus. The purpose of the disc is to separate, protect, and stabilize the condyle in the mandibular fossa during functional movements. The articular disc, however, does not determine positional stability of the joint. As in any other joint, positional stability is determined by the muscles that pull across the joint and prevent separation of the articular surfaces. The directional forces of these muscles determine the optimum orthopedically stable joint position. This is an orthopedic principle that is common to all mobile joints. It might be stated that every mobile joint has a *musculoskeletally stable position*, that being the position stabilized by the activity of muscles that pull across it. The musculoskeletally stable position is the most orthopedically stable position for the joint and can be identified by observing the directional forces applied by the stabilizing muscles.

The major muscles that stabilize the TMJs are the elevators. The direction of the force placed on the condyles by the temporalis muscles is predominantly superior. The temporalis muscles have some fibers that are oriented horizontally; however, because these fibers must transverse around the root of the zygomatic arch, the majority of fibers elevate the condyles in a straight superior direction[2] (Figure 7-1, *A*). The masseter and medial pterygoid muscles provide forces in a superoanterior direction, which seats the condyles superiorly and anteriorly against the posterior slopes of the articular eminences (Figure 7-1, *B*). These three muscle groups are primarily responsible for joint position and stability, although the lateral pterygoid muscles also contribute to joint stability (Figure 7-1, *C*).

In the postural position, without any influence from the occlusal condition, the condyles are stabilized by muscle tonus of the elevator and the inferior lateral pterygoid muscles. The temporalis muscles position the condyles superiorly in the fossae. The masseter and medial pterygoid muscles position the condyles superoanteriorly. Tonus in the inferior lateral pterygoid muscles positions the condyles anteriorly against the posterior slopes of the articular eminences.

Therefore, the most orthopedically stable joint position as dictated by the muscles is described to be when the condyles are located in their most superoanterior position in the articular fossae, resting against the posterior slopes of the articular eminences. This description is not complete, however, until the positions of the articular discs are considered. Optimum joint relationship is achieved only when the articular discs are properly interposed between the condyles and the articular fossae. Thus, the complete definition of the most orthopedically stable joint position is that position when the condyles are in their most superoanterior position in the articular fossae, resting against the posterior slopes of the articular eminences, with the articular discs properly interposed. This position is the *most musculoskeletally stable position* of the mandible.

The most orthopedically stable position just described does not consider the stabilizing effects of the structures at the other end of the mandible—namely, the teeth. The occlusal contact pattern of the teeth also influences stability of the masticatory system. It is important that when the condyles are in their most stable position in the fossae and the mouth is closed, the teeth occlude in their most stable relationship. The most stable occlusal position is the maximal intercuspation of the teeth. This type of occlusal relationship furnishes maximum stability for the mandible while minimizing the amount of force placed on each tooth during function.

In summary, the criteria for optimum orthopedic stability in the masticatory system would be to have even and simultaneous contact of all possible teeth when the mandibular condyles are in their most superoanterior position, resting against the posterior slopes of the articular eminences, with the discs properly interposed. In other words, the musculoskeletally stable position of the condyles coincides with the maximum intercuspal position of the teeth.

One additional consideration in describing the occlusal condition is the fact that the mandible has the ability to move eccentrically, resulting in tooth contacts. These lateral excursions allow horizontal forces to be applied to the teeth, and horizontal forces are not generally well accepted by the dental supportive structures, yet the complexity of the joints requires that some teeth bear the burden of these less tolerated forces. When all the teeth are examined, it becomes apparent that the anterior teeth are better candidates to accept these horizontal forces than posterior teeth because they are farther from the force vectors, which results in less force to these teeth. Of all the anterior teeth the canines are the best suited to accept the horizontal forces that occur during eccentric movements.[3–5] They have the longest and largest roots and therefore the best crown-to-root ratio.[6] They are also surrounded by dense compact bone, which tolerates the forces better than does the medullary bone found around posterior teeth.[7]

The laterotrusive contacts need to provide adequate guidance to immediately disocclude the teeth on the opposite side of the arch (mediotrusive or nonworking side). When the mandible moves forward into a protrusive position, the anterior teeth should also provide adequate contact or guidance to disarticulate the posterior teeth.

The following is a summary of the conditions that provide optimal orthopedic stability in the masticatory system. This represents the orthodontic treatment goals for all patients.

1. When the mouth closes, the condyles should be in their most superoanterior position (musculoskeletally stable), resting against the posterior slopes of the articular eminences with the discs properly interposed. In this position, there should be even and simultaneous contact of all posterior teeth. The anterior teeth may also make contact but more lightly than the posterior teeth.
2. When the mandible moves into laterotrusive positions, there should be adequate tooth-guided contacts on the laterotrusive (working) side to immediately disocclude the mediotrusive (nonworking) side. The canines (canine guidance) provide the most desirable guidance.
3. When the mandible moves into a protrusive position, there should be adequate tooth-guided contacts on the anterior teeth to immediately disocclude all posterior teeth.
4. When the patient sits upright (in the alert feeding position[8]) and is asked to bring the posterior teeth into contact, the posterior tooth contacts should be heavier than anterior tooth contacts.

FINDING THE MUSCULOSKELETALLY STABLE POSITION

Now that the orthopedic treatment goals for all orthodontic therapy have been described, the next question that needs to be asked is, “How can I locate the musculoskeletally stable position of the condyles in the fossae?” For these treatment goals to useful, the clinician must be

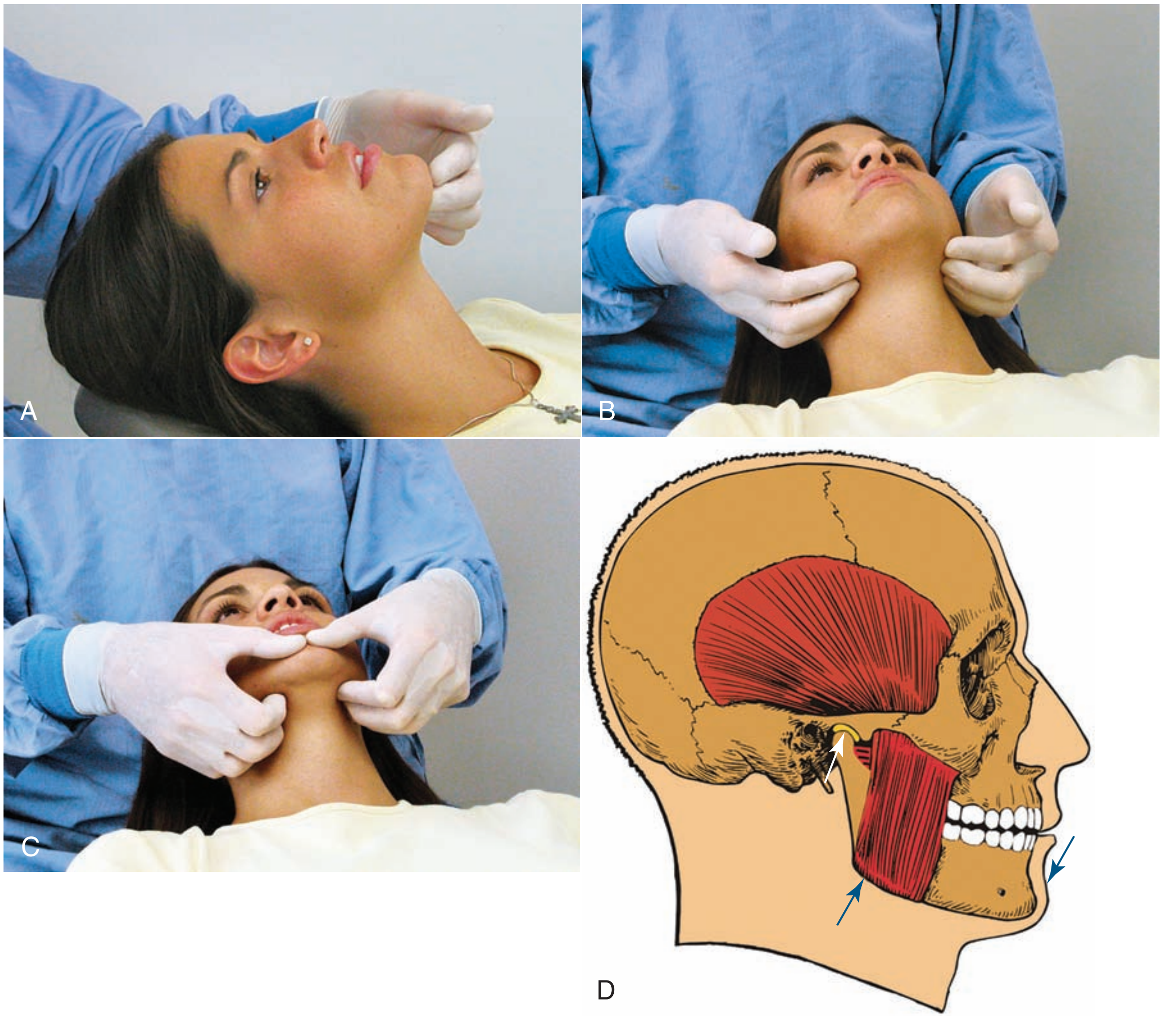

FIGURE 7-2 **A,** Successfully guiding the mandible into the musculoskeletally stable position begins with having the patient recline and directing the chin upward. **B,** The four fingers of each hand are placed along the lower border of the mandible. The small finger should be behind the angle, with the remaining fingers on the inferior border of the mandible. An important point is to place the fingers on the bone and not in the soft tissues of the neck. **C,** The thumbs meet over the symphysis of the chin. **D,** Downward force is applied to the chin (*blue arrow*) while superior force is applied to the angle of the mandible (*blue arrow*). The overall effect is to set the condyle superior anterior in the fossae (*white arrow*).

able to repeatedly and reliably locate this treatment position. An easy and effective method of locating the musculoskeletally stable position is the bilateral manual manipulation technique.[9,10,pp.249–253] This technique begins with the patient lying back and the chin pointed upward (Figure 7-2, *A*). Lifting the chin upward places the head in an easier position to locate the condyles near the musculoskeletally stable position. The dentist sits behind the patient and places the four fingers of each hand on the lower border of the mandible at the angle. The small finger should be behind the angle with the remaining fingers on the inferior border of the mandible. It is important that the fingers be located on the bone and not in the soft tissues of the neck (Figure 7-2, *B*). Next, both thumbs are placed over the symphysis of the chin so they touch each other between the patient's lower lip and chin (Figure 7-2, *C*). When the hands are in this position, the mandible is guided by upward force placed on its lower border and angle with the fingers while at the same time the thumbs press downward and backward on the chin. The overall force on the mandible is directed so that the condyles will be seated in their most superoanterior position braced against the posterior slopes of the eminences (Figure 7-2, *D*). Firm but gentle force is needed to guide the mandible so as not to elicit any protective reflexes.

Locating the musculoskeletally stable position begins with the anterior teeth no more than 10 mm apart to ensure that the temporomandibular ligaments have not forced translation of the condyles. The mandible is positioned with a gentle arcing until it freely rotates around the musculoskeletally stable position. This arcing consists of short movements of 2 to 4 mm. Once the mandible is rotating around the musculoskeletally stable position, force is firmly applied by the fingers to seat the condyles in their most superoanterior position.

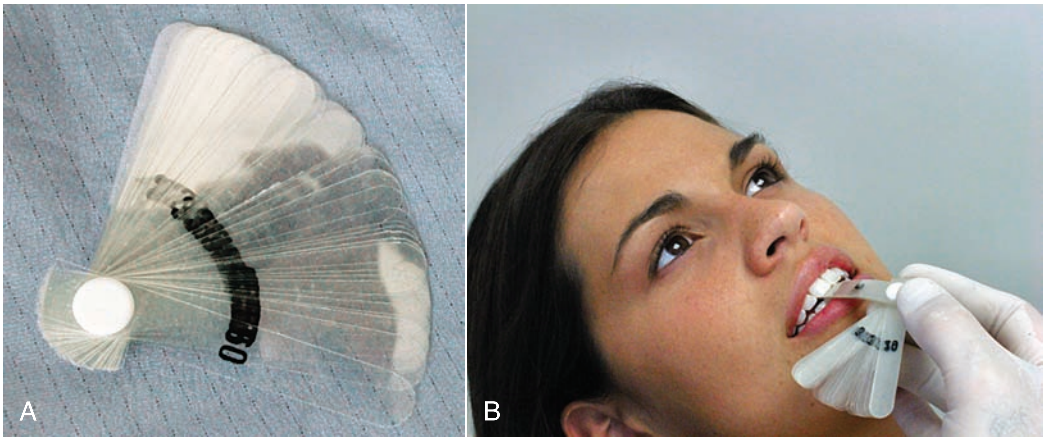

FIGURE 7-3 **A,** A leaf gauge. **B,** The leaf gauge is used to assist in locating the musculoskeletally stable position. The patient is asked to close, and enough leaves are placed between the anterior teeth to separate the posterior teeth slightly. As the patient tries to seat the posterior teeth, the condyles will be seated to the musculoskeletally stable position. One should take care to ensure that the patient does not protrude the mandible while closing or that the leaf gauge does not exert a retruding force on the condyles. Once the position has been located, leaves are removed one at a time so that the initial contact in musculoskeletally stable position can be identified.

In this superoanterior position, the condyle–disc complexes are in proper relation to accept forces. When such a relationship exists, guiding the mandible to this position should not produce pain. If pain is elicited, it is possible that some type of intracapsular disorder exists. When a pain condition exists, an accurate mandibular position will not likely be found. The reason for this pain needs to be investigated and managed before any orthodontic therapy is begun.

Another method of finding the musculoskeletally stable position is by using the muscles themselves to seat the condyles. This can be accomplished with a leaf gauge[10,11] (Figure 7-3). The concept behind a leaf gauge is that when only the anterior teeth occlude (disengaging the posterior teeth), the directional force provided by the elevator muscles (temporalis, masseter, medial pterygoid) seats the condyles in a superoanterior position within the fossae. The anterior stop provided by the leaf gauge acts as a fulcrum, allowing the condyles to be pivoted to the musculoskeletally stable position in the fossae. A leaf gauge must be used carefully, however, so that the condyle will not be deflected away from the stable joint position. If the leaf gauge is too rigid, it may provide a posterior slope, deflecting the mandible posteriorly as the elevator muscles contract. Another error may result if the patient attempts to bite on the leaf gauge in a slightly forward position as if to bite off a sandwich. This will lead to protruding the mandible from the musculoskeletally stable position.

For effective use of the leaf gauge, the patient must attempt to close down on the posterior teeth with mild force. Enough leaves are placed between the anterior teeth to separate the posterior teeth slightly. The patient is instructed to close by trying to use only the temporalis muscles, avoiding any heavy masseter contraction. At first this is a difficult request, but by having the patient place two fingers over these muscles, the examiner can demonstrate how they feel contracting. The patient will quickly learn to contract the temporalis muscles predominantly, which will minimize protrusive forces. Once this has been mastered, the leaves are removed one by one until the teeth become closer. The occlusal relationship then can be evaluated in the musculoskeletally stable position.

Before beginning any orthodontic therapy, the orthodontist should feel confident that the musculoskeletally stable position has been located. Nothing is worse than completing the orthodontic therapy only to learn that the patient was habitually posturing the jaw in a forward position and a duel bite has been developed. This condition does not occur often but being suspicious that it can will help ensure that it does not. If the operator feels unsure in locating the stable mandibular position, orthodontic therapy should be delayed until certainty is established.

Still another condition that should raise suspicion is the presence of a unilateral crossbite. Patients with a unilateral crossbite often shift the mandible to one side during final tooth contact. This shifting may prevent a condyle from being maintained in a stable position in the fossa. The orthodontist should observe the patient while the mouth is being closed for any deviations or deflections as the teeth reach intercuspation. In cases when the shift is great, tomography may be useful in identifying the position of the condyle in the fossa. However, it should be noted that tomograms have limited use in identifying condylar position unless gross positioning abnormalities exist. The reason for this is because tomograms, as with any radiograph, only image subarticular bone and not the soft tissues, which are the true articular surfaces of the joint. Because these tissues can vary in thickness, the condylar position may not appear to be seated when in reality it is in a musculoskeletally stable position. Transcranial and panoramic radiographs are even less reliable for identifying the condylar position in the fossa.

As previously stated, being suspicious that a condyle may not be fully seated is the beginning of developing a successful treatment plan. If the operator has any doubt regarding the location of the musculoskeletally stable position, a stabilization appliance should be fabricated until a stable and reproducible condylar position is found.

Once the musculoskeletally stable position has been reliably located, the relationship of the maxillary and mandibular teeth is observed in this mandibular position. Because the orthodontic treatment goal is to develop the maximum intercuspal position of the teeth in this mandibular position, the orthodontist needs to develop the correct orthodontic strategies that will accomplish this goal. In some instances the orthodontist may find it useful to mount the patient's casts on an articulator to better visualize the occlusal relationship. This may be especially helpful when a significant intraarch discrepancy exists. It is not necessary to mount every orthodontic case on an articulator. In most growing patients, the orthodontic therapy will likely be completed before final maturation of the condyle–fossae relationship. It is important that the orthodontist always be aware of the musculoskeletally stable position of the condyles and finalize the occlusion in relationship to this position. However, final precision of the position is likely accomplished by the physiology of form and function as the young adult matures. In other words, the orthodontist needs to provide an occlusal condition that is within the physiologic tolerance or adaptability of the patient. In a growing patient, it would be reasonable to assume that this is within 1 or 2 mm of the musculoskeletally stable position of the joint. Once the orthodontic therapy is finalized, the patient's individual loading during function will normally assist in stabilizing the masticatory system. The only point in question is how adaptable are the patient's masticatory structures. Of course, this is unknown, and therefore the orthodontist needs to always strive toward developing the occlusal position as close to the musculoskeletally stable position as possible. In difficult cases, the articulator may be useful is achieving this goal. However, it should always be remembered that an articulator is merely a tool that may assist in achieving your goal, not a magical instrument that will ensure success.

In adult patients, it more important to precisely develop the orthopedically stable position because growth is less likely and adaptability may be less. The articulator may be of greater assistance in these cases but, once again, articulators are not always needed. The clinician needs to assess the dental relationship and then determine if an articulator will assist in accomplishing the treatment goals. Remember that the articulator is only as accurate as the operator that takes the records and mounts the casts.

EVALUATING THE PATIENT FOR TEMPOROMANDIBULAR DISORDERS

Because TMD symptoms are common, it is recommended that every orthodontic patient be screened for these problems, regardless of the apparent need or lack of need for treatment. Because orthodontic therapy will likely influence the patient's occlusal condition, it is important to identify any dysfunction in the masticatory system before therapy is ever begun. Knowing the functional condition of the masticatory system in advance helps prepare the patient and the orthodontist to what can be expected after the therapy has been completed. This information also helps develop the most appropriate treatment plan that will minimize dysfunction in future years. Nothing is more disheartening to the orthodontist than to be in the middle of orthodontic therapy and have the patient report that a preexisting TMD symptom was a result of the orthodontic therapy. It greatly behooves the orthodontist to be aware of all conditions in the masticatory system *before* any therapy is begun.

A TMD Screen History

The purpose of the screening history and examination is to identify any TMD signs and symptoms of which the patient may or may not be aware (i.e., headaches, ear pain). The screening history consists of several questions that will help alert the orthodontist to any TMD symptoms. These can be asked personally by the clinician or may be included in the general health and dental questionnaire that the patient completes prior to developing the treatment plan. The following questions can be used to identify functional disturbances[10,pp.216–223]:

1. Do you have difficulty and/or pain opening your mouth, for instance, when yawning?
2. Does your jaw get "stuck," "locked," or "go out"?
3. Do you have difficulty and/or pain when chewing, talking, or using your jaws?
4. Are you aware of noises in the jaw joints?
5. Do your jaws regularly feel stiff, tight, or tired?
6. Do you have pain in or about the ears, temples, or cheeks?
7. Do you have frequent headaches, neckaches, or toothaches?
8. Have you had a recent injury to your head, neck, or jaw?
9. Have you been aware of any recent changes in your bite?
10. Have you previously been treated for any unexplained facial pain or a jaw joint problem?

If a patient reports positively to any of these questions, the clinician should request additional information that clarifies the condition.

A TMD Screen Examination

A screening examination should accompany the screening history.[10] This should be relatively brief and is an attempt to identify any variation from normal anatomy and function. It begins with an inspection of the facial symmetry. Any variation from the general bilateral symmetry should raise suspicion and indicate the need for further examination. The screening examination should include the palpation of facial muscle and the TMJs as well as observations of jaw movement. The occlusal condition should also be evaluated with respect to the orthopedically stable position of the joint.

Muscle Palpation. Several important muscles of the masticatory system are palpated for pain or tenderness during the screening examination. The temporalis and masseter muscles are palpated bilaterally (Figures 7-4 and 7-5). Palpation of the muscle is accomplished mainly by the palmar surface of the middle finger, with the index finger and forefinger testing the adjacent areas. Soft but firm pressure is applied to the designated muscles, the fingers compressing the adjacent tissues in a small circular motion. A single firm thrust of 1 or 2 seconds' duration is usually better than several light thrusts. During palpation the patient is asked whether it hurts or is just uncomfortable.

For the muscle examination to be most helpful, the degree of discomfort is ascertained and recorded. This is often a difficult task. Pain is subjective and is perceived and expressed quite differently from patient to patient. Yet the degree of discomfort in the structure can be important to recognizing the patient's pain problem as well as an excellent method of evaluating treatment effects. An attempt is made therefore not only to identify the affected muscles but also to classify the degree of pain in each. When a muscle is palpated, the patient's response is placed in one of four categories.[12,13] A zero (0) is recorded when the muscle is palpated and there is no pain or tenderness reported by the patient. A number 1 is recorded if the patient responds that the palpation is uncomfortable (tenderness or soreness). A number 2 is recorded if the patient experiences definite discomfort or pain. A number 3 is recorded if the patient shows evasive action or eye tearing or verbalizes a desire not to have the area palpated again. The pain or tenderness of each muscle is recorded on an examination form, which will assist diagnosis and later be used in the evaluation and assessment of progress.

TMJ Palpation. The TMJs are examined for any signs or symptoms associated with pain and dysfunction. Pain or tenderness of the TMJs is determined by digital palpation of the joints when the mandible is both stationary and during dynamic movement. The fingertips are placed over the lateral aspects of both joint areas simultaneously (Figure 7-6, *A*). If uncertainty exists regarding the proper position of the fingers, the patient is asked to open and close a few times. The fingertips should feel the lateral poles of the condyles passing downward and forward across the articular eminences. Once the position of the fingers over the joints has been verified, the patient relaxes and medial force is applied to the joint areas. The patient is asked to report any symptoms, and they are recorded with the same numerical code that is

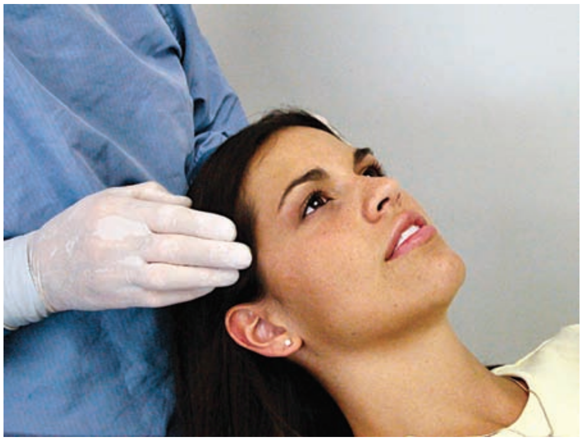

FIGURE 7-4 Palpation of the temporalis muscle.

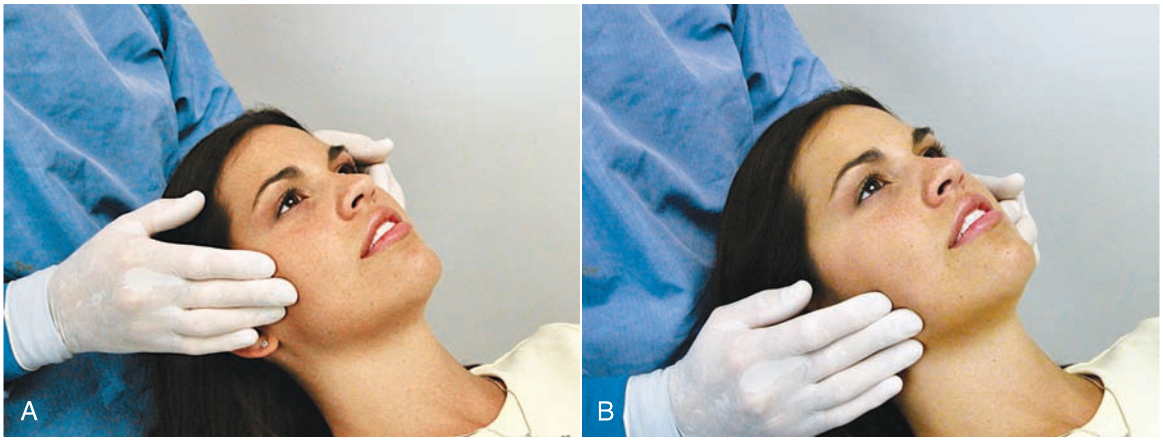

FIGURE 7-5 **A,** Palpation of the masseter muscle near its attachment to the zygomatic arch. **B,** Palpation of the masseter muscle near its attachment to the lower border of the mandible.

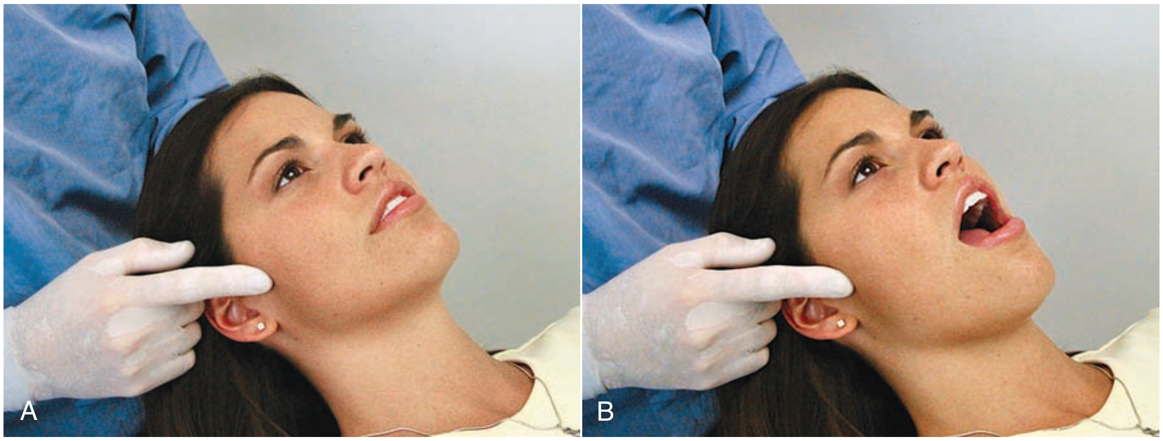

FIGURE 7-6 **A,** Palpation of the temporomandibular joint in the closed-mouth position. **B,** Palpation of the temporomandibular joint in the opened-mouth position.

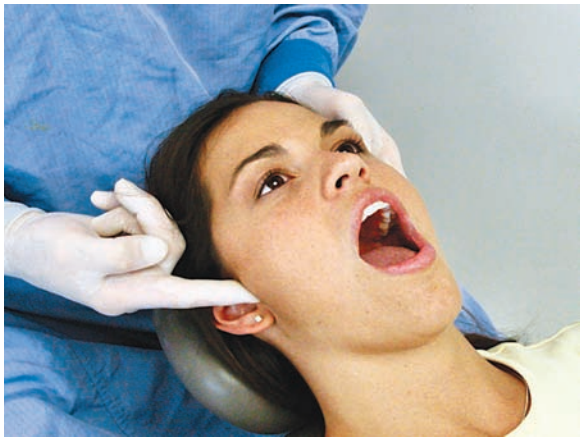

FIGURE 7-7 Palpation of the temporomandibular joint with the mouth fully open. The finger is moved behind the condyle to palpate the posterior aspect of the joint.

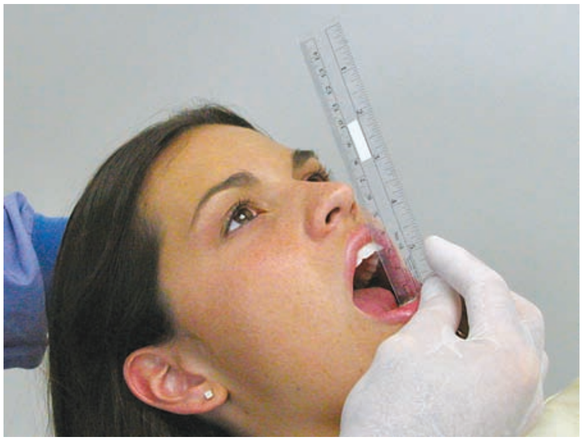

FIGURE 7-8 Measuring the interincisal distance during maximum mouth opening.

used for the muscles. Once the symptoms are recorded in a static position, the patient opens and closes and any symptoms associated with this movement are recorded (Figure 7-6, *B*). As the patient opens maximally, the fingers should be rotated slightly posteriorly to apply force to the posterior aspect of the condyle (Figure 7-7). Posterior capsulitis and retrodiscitis are clinically evaluated in this manner.

Joint sounds are recorded as either clicks or crepitation. A click is a single sound of short duration. If it is relatively loud, it is sometimes referred to as a pop. Crepitation is a multiple gravel-like sound described as grating and complicated. Crepitation is most commonly associated with osteoarthritic changes of the articular surfaces of the joint.[14–17]

Joint sounds can be perceived by placing the fingertips over the lateral surfaces of the joint and having the patient open and close. Often they may be felt by the fingertips. A more careful examination can be performed by placing a stethoscope over the joint area. Not only should the character of any joint sounds be recorded (clicking or crepitation) but also the degree of mouth opening associated with the sound. Of equal importance is whether the sound occurs during opening or closing or can be heard during both these movements.

It is not wise to examine the joint for sounds by placing the fingers in the patient's ears. It has been demonstrated that this technique can actually produce joint sounds that are not present during normal function of the joint.[18] It is thought that this technique forces the ear canal cartilage against the posterior aspect of the joint and either this tissue produces sounds or this force displaces the disc, which produces the additional sounds.

Range of Mandibular Movement. A screening examination should also include evaluation of the patient's range of mandibular movement. The normal range[19–21] of mouth opening when measured interincisally is between 53 and 58 mm. Even a 6-year-old child can normally open a maximum 40 mm or more.[22,34] The patient is asked to open slowly until pain is first felt (Figure 7-8). At that point, the distance between the incisal edges of the maxillary and mandibular anterior teeth is measured. This is the maximum comfortable opening. The patient is next asked to open the mouth

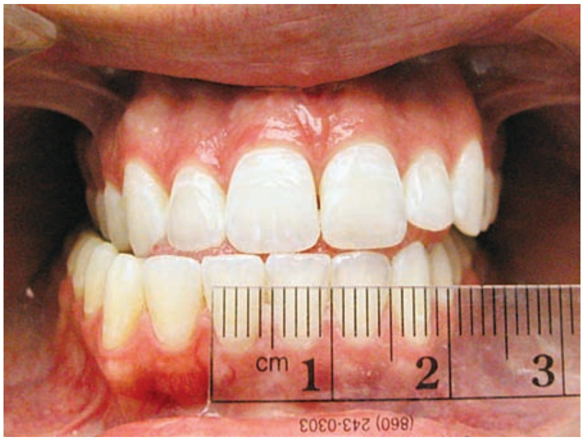

FIGURE 7-9 Measuring the distance of eccentric mandibular movement.

maximally. This is recorded as the maximum opening. In the absence of pain the maximum comfortable opening and maximum opening are the same.

A restricted mouth opening is considered to be any distance less than 40 mm. Only 1.2% of young adults[22] open less than 40 mm. Less than 40 mm of mouth opening, therefore, seems to represent a reasonable point to designate restriction but one should always consider the patient's age and body size.

The patient is next instructed to move his or her mandible laterally. A lateral movement less than 8 mm is recorded as a restricted movement (Figure 7-9). Protrusive movement is also evaluated in a similar manner.

Occlusal Evaluation. The occlusal examination[10] begins with an observation of the occlusal contacts when the condyles are in their optimum orthopedic position (musculoskeletally stable position). As already described, this position is located by using a bilateral manual manipulation technique. In this position the mandible can be purely rotated opened and closed approximately 20 mm interincisally while the condyles remain in their musculoskeletally stable position. Once the musculoskeletally stable position is located and the mandible is brought into tooth contact, the occlusal relationship of the teeth in this joint position is evaluated. Once tooth contact is achieved, the patient is asked to hold the mandible on the first occlusal contact and the relationship of the maxillary and mandibular teeth is noted. Then the patient is requested to apply force to the teeth, and any shifting of the mandible is observed. If the occlusion is not stable in the musculoskeletally stable position, a shifting will occur that carries the condyles away from their orthopedically stable positions to the more stable maximum intercuspal position. This shifting represents a lack of orthopedic stability.

It is important to observe the horizontal and vertical components of the slide. Some slides occur in a straight anterosuperior direction into an intercuspal position. Others have a lateral component. It has been reported[24,25] that slides that deflect the mandible to the left or right are more commonly associated with dysfunction than are slides that create a straight anterovertical movement. The distance of the slide is also important in that slides greater than 3 to 4 mm have been associated with increased incidence of TMD symptoms. Conversely, slides of 1 to 2 mm or less, which are very common, do not seem to be related to TMD symptoms. If the patient is asked to apply force to the teeth and no shift occurs, the intercuspal position is said to be coincident with musculoskeletally stable position.

If the screening history and examination reveal positive findings, a more thorough history and examination for TMDs is completed. A thorough TMD examination can be found in other sources.[10]

The Clinical Significance of Joint Sounds. Joint sounds most commonly occur as a result of disc displacements.[10] When the disc is displaced during mouth opening, an abnormal translatory movement can occur between the condyle and the disc, causing a clicking sound. Although disc displacements are considered abnormal, they are certainly not uncommon. The published prevalence of disc displacement in asymptomatic children and young adults is approximately 30%.[26] Recent studies suggest that a majority of adolescent preorthodontic patients, regardless of gender, present with some disc displacement.[27,28] The question that needs to be asked is, "Does the click represent pathology?" Often clicks occur in the absence of any pain or signs of progression. In a very interesting study by Magnusson et al.,[29] joint sounds were recorded in a 15-year-old population and then again in the same population at age 20. Of the 35 subjects who had sounds at age 15, 16 (or 46%) no longer had them at age 20. None of these subjects were provided any treatment. It was also interesting to note in this study that of the 38 participants aged 15 years who did not have joint sounds, 19 (or 50%) did have joint sounds at age 20. These data suggest that a 15-year-old with TMJ sounds has a 46% chance the sound will resolve without treatment by the age of 20. The study also suggests, however, that if a 15-year-old does not have TMJ sounds, there is a 50% chance he or she will acquire a sound by age 20. The authors concluded that joint sounds come and go and are often unrelated to major masticatory symptoms. Both 10- and 20-year follow-up examinations of this same population continue to reveal the lack of a significant relationship between joint sounds and pain or dysfunction.[30,31]

In a similar study, Kononen et al.[32] observed 128 young adults longitudinally over 9 years at ages 14, 15, 18, and 23 years. They reported that although clicking did increase significantly with age from 11% to 34%, there was no predictable pattern and only 2% of subjects showed consistent findings during the periods of evaluation. They found no relationship between clicking and the progression to locking.

A significant long-term study by de Leeuw et al.[33] found that 30 years after nonsurgical management of intracapsular disorders, joint sounds persisted in 54% of the patients. Although these findings reveal that joint sounds remain in many patients, it is important to note that none of these patients was experiencing any discomfort or even dysfunction from the joint condition. This study, like the others referenced here, suggests that joint sounds are often not associated with pain or even major TMJ dysfunction. This research group[32–34] also found that long-term osseous changes in the condyle were commonly associated with disc dislocation without reduction and not so commonly associated with disc dislocation with reduction. Yet even in the patients with significant alterations in condylar morphology (osteoarthrosis), little pain and dysfunction were noted.[35]

Studies such as these suggest that joint sounds are not always progressive and therefore may not need to be treated. Several studies[32,36–40] report that progression of intracapsular disorders as determined by joint sounds only occurs in 7% to 9% of the patients with sounds. One study suggests, however, that if the disc derangement disorder results in significant catching or locking, the chance that the disorder will progress is much greater.[41]

The long-term studies certainly suggest that joint sounds are not necessarily a significant problem for most patients. However, the majority of these studies have evaluated adult populations. What about a young adult who will be undergoing significant occlusal changes with orthodontic treatment? This may pose a different question for the orthodontist. Certainly the orthodontist who is trying to achieve orthopedic stability in the masticatory structures needs to be able to assess the status of the TMJs prior to treatment.

Animal studies demonstrate if a disc displacement is surgically induced, histologic changes are observed in the condylar cartilage.[42] In this study, the investigators also noted that the condylar cartilage on the contralateral control side was also affected, although to a lesser degree. In studies conducted by Legrell and Isberg,[43] surgically induced unilateral disc displacement without reduction in animal models resulted in developmental facial asymmetry. Animals subjected to bilateral disc displacement developed Angle Class II relationship. These results demonstrate that alterations in the disc position can influence three-dimensional growth patterns of the condyle. Similarly, experimentally induced disc displacements without reduction in growing animals have been shown to actually hinder mandibular growth relative to controls, and the negative effects were greater on anterior and superior growth of the mandible while posterior growth was relatively unaffected.[44] According to Björk and Skieller,[45] bone apposition on the posterior aspect of the condyle causes clockwise rotation of the mandible, resulting in a receded chin and an open bite, which would be an unfavorable situation for orthodontic treatment.

Although these experimental studies suggest that disc displacements can lead to condylar changes, the question remains on a clinical level how often this occurs in the young adult. This question is very important but difficult to determine. The musculoskeletal system is adaptive, especially in this young population. It is very likely that the individual with a disc displacement will adapt to this change and show little clinical consequence. However, this may not be true for every patient. Therefore, it is important for the orthodontist to evaluate the health of the TMJs prior to any treatment. As a general rule, individuals who are having a problem with adaption have a greater degree of pain and dysfunction. Therefore, if the history and examination reveal any pain or significant dysfunction, more investigation is indicated.

If the examination determines the presence of pain or significant dysfunction, additional information may be needed. Images such as cone beam CT or MRIs may be able to provide more information. Cone beam CT three-dimensionally visualizes morphologic alterations in bony structures, degenerative changes, and, to some degree, the position of the condylar within the fossa.[46] Magnetic resonance images (MRIs) can identify disc displacement and its degree, location, and direction. MRIs can also detect certain disc conditions such as hypertrophy, and T2-weighted images visualize joint effusion. These data may be useful in understanding the health of these tissues. The interpretation of diagnostic images will be described later in detail through a clinical case.

For patients who exhibit TMD symptoms, abnormality in images, unstable jaw position, and/or facial asymmetry, the orthodontist should consider resolving the TMD symptoms and stabilizing the joint position before any orthodontic therapy is begun. A stabilization appliance may be useful in reducing the TMD symptoms. With this appliance, the causal relationship between the patient's occlusion and TMD symptoms can be better appreciated (as will be discussed later in this chapter). Improvement in soft and hard tissues of the TMJs can also be expected during the occlusal appliance therapy, providing a repeatable and stable jaw position. With a stabilized joint, the orthodontist can develop a treatment plan that will provide optimum occlusal contacts in this position (orthopedic stability).

DEVELOPING THE ORTHODONTIC/TEMPOROMANDIBULAR JOINT DISORDER TREATMENT PLAN

All potential orthodontic patients should be evaluated for both their aesthetic and functional needs. Once the history and examination data are collected, this information is used to develop a treatment plan that will appropriately meet the overall needs of the patient. When considering the possibilities, the patient can have either only aesthetic needs, only TMD needs, or both aesthetic and TMD needs. The type of needs determines the treatment sequence. When the patient has only esthetic needs, the clinician need only consider the best therapy to fulfill the orthodontic goals. Included with these goals, of course, are not only the best mechanics to move teeth but also the goals of achieving orthopedic stability that have already been presented in this chapter.

When a patient presents with only TMD symptoms, the clinician should not assume that orthodontic therapy will be a part of the treatment plan. Orthodontic therapy is only indicated for TMD patients when it has been determined that orthopedic instability is present and this instability is contributing to the TMD. The mere presence of orthopedic instability is not sufficient evidence to be certain that it is contributing to the TMD. Many individuals have orthopedic instability without any functional complaints or complications. Therefore, when TMD symptoms are present, the clinician should first attempt to determine if the orthopedic instability is contributing to the TMD. The best way to identify this relationship is by first providing orthopedic stability reversibly with an occlusal appliance. If the occlusal appliance adequately provides the desirable stability but does not reduce the TMD symptoms, it can be assumed that orthopedic stability is not related to the symptoms and orthodontic therapy should not be considered for this patient. It is important to remember that orthodontic therapy can only affect TMD symptoms by changing the occlusal contact pattern of the teeth and the resulting function of the masticatory system.

If an occlusal appliance successfully reduces the TMD symptoms, the clinician often assumes that the occlusion and its relationship to orthopedic instability is an etiologic factor in the TMD. Although this may be true, it makes an assumption that the only manner in which an occlusal appliance affects TMD symptoms is by altering the patient's occlusion. This is a very naive assumption. In fact, there are several factors that may explain how occlusal appliances reduce symptoms associated with TMDs. Consider the following factors:

1. *Alteration of the occlusal condition:* All occlusal appliances temporarily alter the existing occlusal condition. A change, especially toward a more stable and optimum condition, generally decreases protective muscle co-contraction, leading to a reduction of symptoms.
2. *Alteration of the condylar position:* Most appliances alter condylar position to either a more musculoskeletally stable or a more structurally compatible and functional position. This effect on the joint stability can be responsible for a decrease in symptoms.
3. *Increase in the vertical dimension:* All interocclusal appliances increase the patient's vertical dimension while they are being worn. This effect is universal regardless of treatment goals. It has been demonstrated that increases in vertical dimension can temporarily decrease muscle activity[47–49] and symptoms.[50]
4. *Cognitive awareness:* Patients who wear occlusal appliances become more aware of their functional and parafunctional behavior. The appliance acts as a constant reminder to alter activities that may affect the disorder. As cognitive awareness is increased, factors that contribute to the disorder are decreased. The result is a decrease in symptoms.[51–53]
5. *Placebo effect:* As with any treatment, a placebo effect can result.[54,55] Studies[56–59] suggest that up to 40% of the patients with certain TMDs respond favorably to such treatment. A positive placebo effect may result from the competent and reassuring manner in which the doctor approaches the patient and provides the therapy. This favorable doctor-patient relationship, accompanied by an explanation of the problem and reassurance that the appliance will be effective, often leads to a decrease in the emotional state of the patient, which may be the significant factor responsible for the placebo effect.
6. *Increased peripheral input to the central nervous system (CNS):* Evidence suggests that nocturnal muscle hyperactivity appears to have its source at the CNS level.[10,60,61] Any change at the peripheral input level seems to have an inhibitory effect on this CNS activity.[10,62] When an occlusal appliance is placed between the teeth, it provides a change in peripheral input and thus decreases CNS-induced bruxism. The appliance does not cure bruxism; it only inhibits the bruxing tendency while it is being worn. Studies[63–65] show that even with long-term use of an appliance, bruxism seems to return.
7. *Regression to the mean*: Regression to the mean is a statistical term that addresses the common fluctuation of symptoms associated with chronic pain conditions.[66] If one follows the musculoskeletal symptoms of a particular patient, it will be observed that the intensity of pain will usually vary on a daily basis. Some days will be quite painful while other days are more tolerable. If the patient is asked to rate the intensity of his pain each day on a visual analog scale with 0 being "no pain" and 10 being the "worse possible pain ever," the patient may report an average day to be 3. This would represent his mean pain score. However, some days the pain may reach a 7 or 8 but then often with time the pain returns to its mean level of 3. Patients most commonly report to the dental office when the pain intensity is great because that is often the factor that motivates them to seek treatment. When the clinician provides therapy (such as an occlusal appliance) and the symptoms reduce to the average level of 3, one must question if the reduction of symptoms was actually the therapeutic effect of the treatment or if the patient's symptoms merely "regressed to the mean." This factor can be very confusing to the clinician and may lead

> to misdirection of future treatment. Uncontrolled short-term studies that report success of various therapies need to be questioned regarding their actual effect. Is it actually the therapeutic effect of the modality, or was it regression to the mean? The importance of well-controlled, blinded studies become obvious when attempting to answer this question.[55]

When a patient's symptoms are reduced by occlusal appliance therapy, each of these seven factors must be considered as responsible for the success. All permanent (irreversible) treatment should be delayed until significant evidence exists to determine which factor or factors were important in reducing the symptoms. This can be accomplished by first allowing the patient to wear the appliance for 1 to 2 months to ensure that the symptoms have been adequately controlled. It should be noted that the appliance may not need to be worn 24 hours per day.[67] Many patients do very well with only part-time use, most commonly at night. The amount of time needed is dependent on the type of TMD that is being treated.[10] Once the patient is comfortable for several weeks, perhaps months, the patient should be asked to reduce the use of the appliance. In many instances, the patient can discontinue use of the appliance and not experience a return of symptoms. When this occurs, factors that relate to dental etiology, such as the occlusal condition, condylar position, or vertical dimension, are not likely the causes of the TMD. When this occurs, the patient should be encouraged to wear the appliance occasional as needed to manage any return in symptoms secondary to bruxism or emotional stress. These patients do not need orthodontic therapy.

If reducing the use of the occlusal appliance reestablishes the original symptoms, then factors such as the occlusal condition, condylar position, or vertical dimension may need to be considered as potential etiologic factors. But which factor is the likely cause? This question needs to be answered before any therapy begins. If the clinician is suspicious that the vertical dimension is the etiology of the TMD symptoms, then an attempt should be made to verify this assumption. The appliance should be gradually thinned while maintaining the same occlusal contacts and condylar position. The significance of the vertical dimension is confirmed if the symptoms return as the appliance is thinned. However, if the symptoms do not return as the appliance reaches the original vertical dimension, the clinician should be more suspicious that the factors responsible for the reduction of symptoms are either the occlusal condition or the condylar position. It is now important to realize that these two remaining factors are accessed together by evaluating the patient's orthopedic stability. The patient's mandible should be bilaterally manipulated to the musculoskeletally stable position and the occlusal contact pattern assessed. At this time the clinician will now be able to observe the orthopedic instability and have some reasonable clinical certainty that this condition is contributing to the TMD symptoms. Because the clinical evidence now suggests that a change in the occlusal condition would likely reduce the TMD symptoms, the clinician should accurately mount the patient's study casts on an articulator and determine the most appropriate method of achieving the goals of orthopedic stability (i.e., orthodontic therapy).

By way of summary, although occlusal appliances may have some diagnostic value, conclusions regarding the rationale for their success must not be hastily made. Before any orthodontic treatment plan for TMD is begun, ample evidence must exist that the treatment will be of benefit to the patient. In reality, only a select group of TMD patients benefit from orthodontic therapy.

The last situation to be discussed is the patient with TMD who also has aesthetic needs. When patients have both needs, the clinician's first efforts should be directed toward resolving the TMD symptoms. The clinician may decide to use an occlusal appliance to help reduce the symptoms. When an appliance is used, it will not only help reduce symptoms but also assist in locating the musculoskeletally stable position of the joint. Once the symptoms are reduced, the orthodontic treatment plan is developed with respect to the musculoskeletally stable position of the joints and therapy can begin. A clinical case is presented at the end of this chapter to illustrate this type of treatment strategy.

MANAGING TEMPOROMANDIBULAR DISORDER SYMPTOMS THAT ARISE DURING ORTHODONTIC THERAPY

Occasionally, a patient will present with TMD symptoms while actively undergoing orthodontic therapy. This may pose a challenge to the orthodontist. These symptoms may demand immediate attention, yet traditional TMD therapy would be difficult and likely delay the orthodontic treatment plan. Therefore, the orthodontist needs to have some treatment strategies that will help reduce the patient's symptoms.

The first important consideration with a patient who develops new TMD symptoms is to review the orthodontic progress toward achieving orthopedic stability in the masticatory system. This is especially important if the TMD symptoms are related to intracapsular concerns such as joint clicking. The orthodontist should locate the musculoskeletally stable position of the condyles using a bilateral manual manipulation technique and determine if the orthodontic therapy is moving toward developing a favorable intercuspal position in this stable joint position. If it is determined that this goal is not being achieved, the orthodontic treatment plan should be redirected in a manner to better accomplish this goal.

Once it is determined that the direction of treatment is correct but not yet achieved because orthodontic therapy has not been finalized, the patient's specific symptoms can be addressed. The response to symptoms should be appropriate for the type and intensity of the patient's complaints. Although the management of muscle pain disorders is often different than that of intracapsular disorders, some general treatment strategies can be used to manage both. Much of this management is conservative and easily applied to the patient.

One of the most important things the orthodontist can do for the patient is to provide education. The patient needs to know that TMD symptoms are common and benign. They do not shorten one's life. The nature course of most TMD is to experience fluctuations of symptoms, often resolving with little to no significant treatment. Therefore, informing the patient of these can be very therapeutic. Because emotional stress can be an etiologic factor of TMD, often, worrying about the problem makes the problem even worse.

Education is also important because it can be used to actively bring the patient to the treatment that can help them the most. Some simple behavioral interventions can be most helpful. For example, advising the patient to reduce jaw use to within painless limits goes a long way in symptom reduction. The patient should be instructed to eat softer foods, smaller bites and slower chewing. Do not let it hurt. Increased pain can maintain the pain cycle, which may prolong the pain experience.[10] Often, patients are chewing gum or biting on pencils or their fingernails. These activities can further enhance muscle pain. The patient needs to be informed that it is common to put the teeth together even at times when they are unaware of doing so. Bruxing and clenching the teeth are good examples of such activity. Making the patient aware of these activities (cognitive awareness) is the beginning of therapy. Once the patient is aware, the patient should be instructed that at any time he catches himself with the teeth in contact and he is not chewing or swallowing, he should immediately buff a little air between the lips and teeth, let the jaw relax, and then allow the lips to seal. This will place the mandible in the postural position, disengaging the tooth. This position minimizes muscle activity and joint loading. Although this technique seems too simple to work, it has been demonstrated to be very effective in reducing TMD symptoms.[68] The concept of "lips together and teeth apart" is powerful in reducing most acute TMD pains.

If the acute TMD symptoms are associated with pain, the clinician may wish to suggest a mild analgesic be used for 5 to 7 days to reduce the pain. As previously mentioned, pain can reinforce the condition beginning cyclic muscle pain.[10] Mild analgesics can be used to break this cycle. A nonsteroidal anti-inflammatory drug such as ibuprofen can be very useful. It should not be taken only as needed because it will not effectively break the pain cycle. Therefore, the patient should be instructed to take 600 mg of ibuprofen three times a day with meals for 5 or 6 days. Most individuals can tolerate this medication without problems, but if there is a history of gastrointestinal upset, other options should be used.

Another very conservative therapy for muscle pain is moist heat. A moist hot towel can be placed over the painful muscle(s) for 15 to 20 minutes and repeated several times a day as needed. This therapy can be very helpful in reducing acute muscle pain.

Still another option that may be considered relates to sleep quality. If the patient reports poor sleep quality and is waking up with increased pain, one may be suspicious of sleep-related bruxism. When this occurs, a mild muscle relaxant such as cyclobenzaprine 5 to 10 mg before sleep may be helpful. This may be needed for only 5 to 7 days.

For many acute TMD symptoms, these simple therapeutic interventions will be adequate to resolve the condition. There is no need to alter the orthodontic treatment. The patient should be reassessed in 7 to 10 days to make sure the symptoms have been resolved. Once the symptoms have resolved, continue with the orthodontic therapy with the goals of establishing orthopedic stability and aesthetically acceptable appearance.

If in 10 days the symptoms have not adequately resolved, additional steps may be needed. Continue to reinforce the important behavioral aspects of resting the masticatory systems but also consider other factors that may help reducing muscle activity. If the patient is wearing interarch elastics, they should be temporally discontinued. Some patients have a tendency to play with these elastics, causing further muscle activity. Also, it may be time to consider temporary methods of disengaging the teeth during sleep. Making a stabilization appliance may be difficult with all the orthodontic brackets and wires, so on a short-term basis, one can consider a more generic soft appliance.[69,70] These appliances do not require individual fabrication, making them easy to use with orthodontic brackets and wires. Although these types of appliance have not been shown to be as effective as more traditional hard stabilization appliances, they can certainly be used for a brief period of time to, hopefully, reduce acute TMD symptoms.

The patient should again be reevaluated in 1 to 2 weeks for symptom reduction. If the TMD symptoms have resolved, proceed with the orthodontic treatment plan. If the symptoms have still not resolved, a more significant TMD seems to be present and therefore a more traditional approach to management may be needed. At that time, the orthodontist may need to discontinue the active orthodontic therapy by removing the archwire and fabricating a more traditional stabilization appliance. The stabilization appliance should provide even contact of all teeth on flat surfaces when the condyles are in the musculoskeletally stable position (orthopedic stability). Eccentric guidance is provided by the canines. This appliance may be a little more difficult to fabricate with the orthodontic brackets in place but certainly not impossible. The brackets can be blocked out

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As mentioned earlier, a patient can report to the orthodontist's office in one of three general categories: (1) only aesthetic needs, (2) only TMD needs, or (3) both aesthetic and TMD needs. This third group of patients is certainly the most challenging to the orthodontists. In an attempt to illustrate management considerations for this type of patient, the following case report is presented.

A 12-year 11-month-old Asian girl presented to the orthodontic office with her mother. Her chief complaint was crowded teeth and poor aesthetics (Figures 7-10 and 7-11). She did not initially report any masticatory pain or dysfunction. To maximize the benefit of the orthodontic treatment, such as achieving a healthy function of the jaw, a thorough examination was conducted to investigate the presence of any TMD-related signs or symptoms. The clinical evaluation began with a thorough history to reveal any TMD symptoms and was followed by a clinical examination. The patient reported several sources of discomfort, including a clicking sound in the right TMJ that began about 1.5 years earlier. She also reported a general tightness of her facial muscles, which was occasionally associated with limited mouth opening. She reported that she had experienced right TMJ area pain for about 1 year, but it had subsided prior to her initial visit to

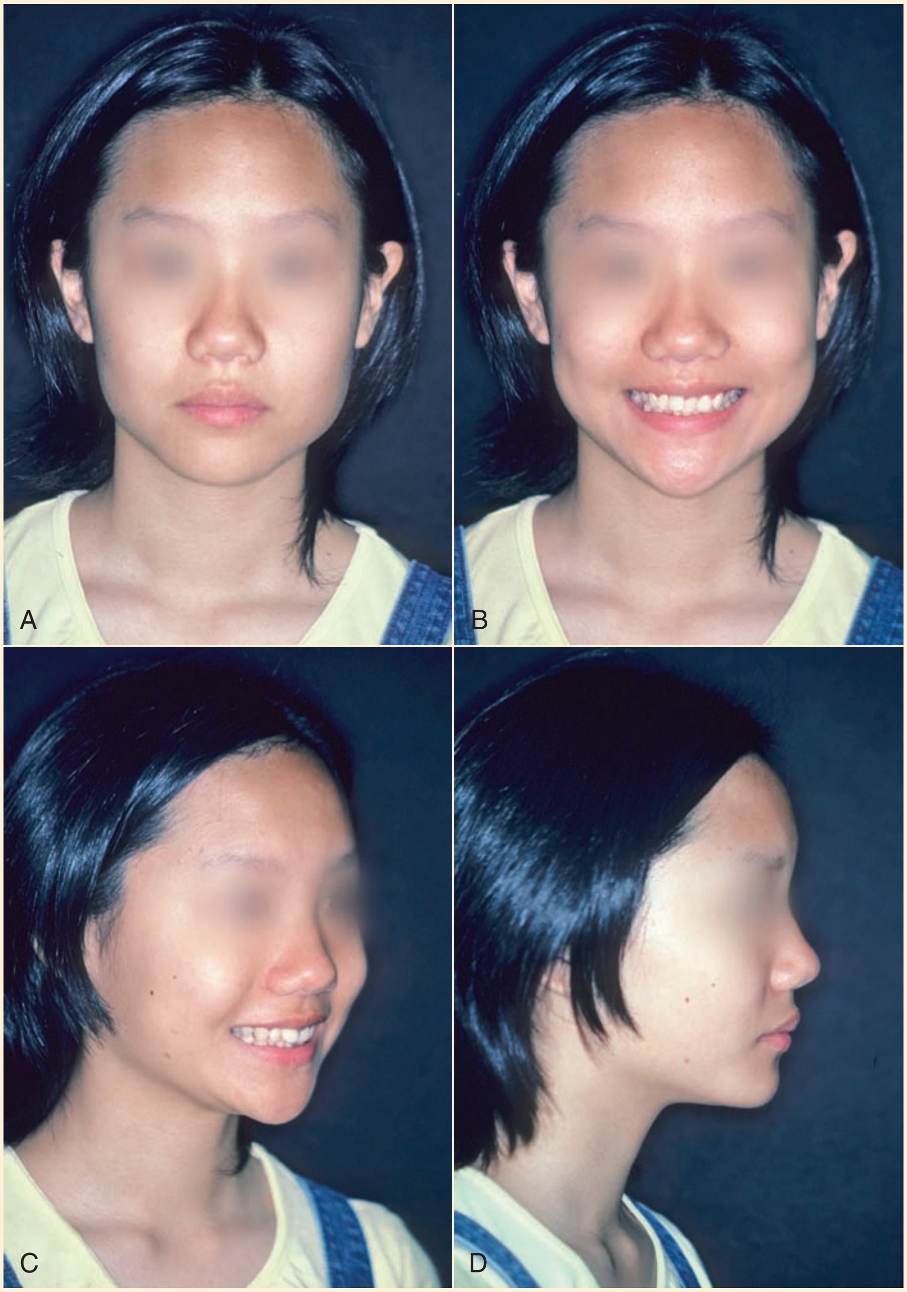

FIGURE 7-10 **A–D,** Initial facial photographs of a girl aged 12 years 11 months. Note the hypertrophic masseter muscles and slight mandibular shift toward right.

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the orthodontic clinic. She reported no previous history of trauma to the face.

The examination revealed muscle tightness and mild pain with palpation of the left and right masseter and temporalis muscles. The comfortable mouth opening was 25 mm with a maximum opening of 41 mm. In the right TMJ, a clicking sound was noted when the mandible shifted toward right. Clicking occurred in the left TMJ at an opening of 30 mm, when the mandible shifted toward left, and at the end of closing. The occlusal examination revealed significant maxillary and mandibular anterior tooth crowding with an Angle Class II molar relationship. In a musculoskeletally stable joint position, there was a significant 3-mm shift of the mandible forward toward the right into the maximum intercuspal position. The patient's casts were mounted in the musculoskeletally stable position to more completely evaluate the occlusion (Figure 7-12). MRI and cone beam computed tomography (CT) images were also taken (Figure 7-13). These images reveal bilateral slight lateral disc displacements. Also, the lateral aspects of both condyles were slightly flattened. Asymmetry of mandible (shifting toward right) was also seen on initial posteroanterior cephalogram (Figure 7-14).

Five diagnoses were then established: (1) masticatory myalgia, (2) right and left side disc displacement with reduction, (3) orthopedic instability, (4) malocclusion/tooth crowding, and (5) upper lip protrusion.

A treatment plan was developed with the initial goal of resolving the TMD symptoms and stabilizing the mandibular position. A stabilization appliance was fabricated initially for nighttime use (nocturnal bruxism). Within 2 months, the patient reported nearly 80% of her symptoms had been controlled, including a significant reduction of the joint sounds. However, she reported that after wearing

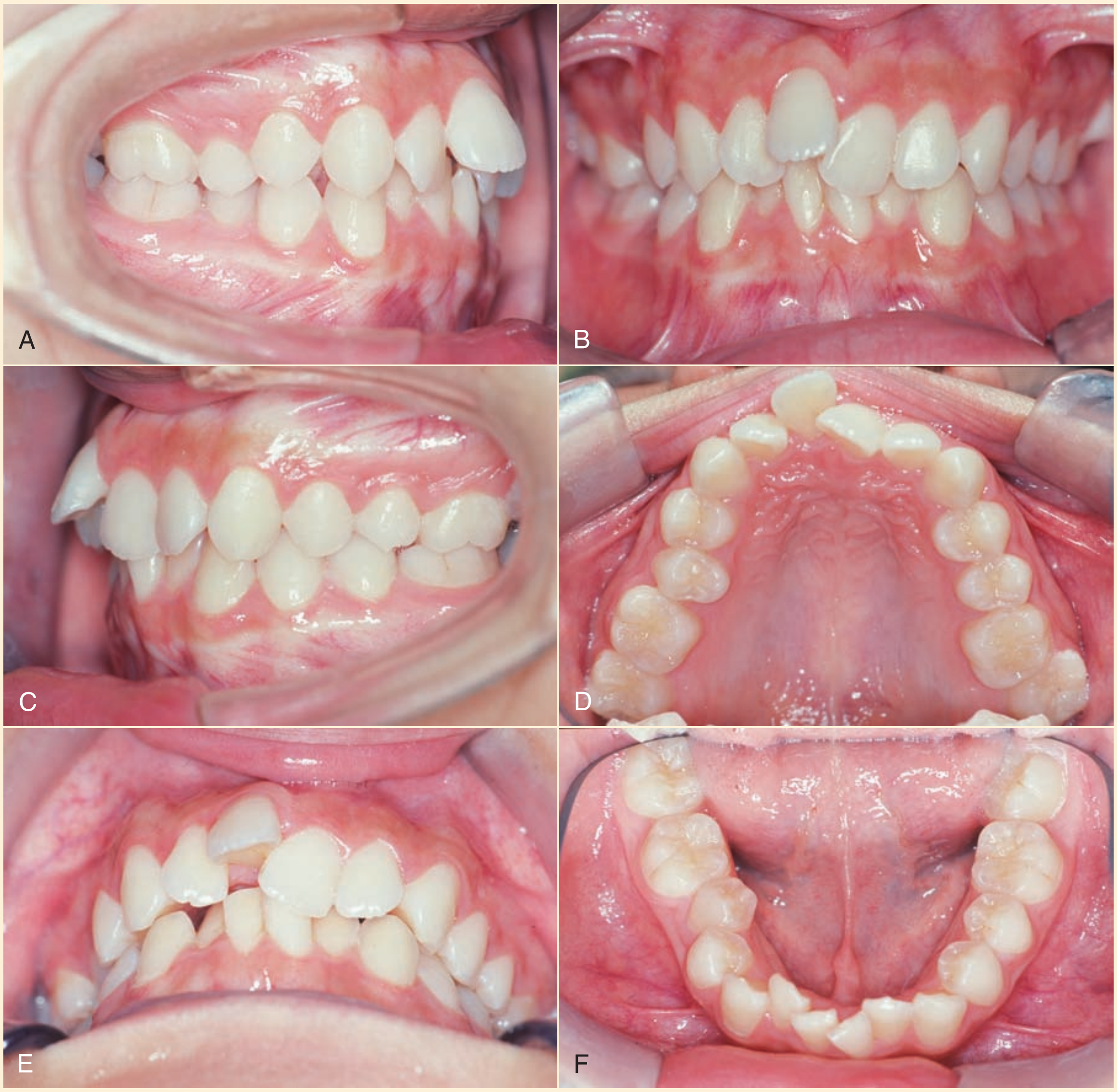

FIGURE 7-11 **A–F,** Initial intraoral photographs.

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CASE STUDY 7-1

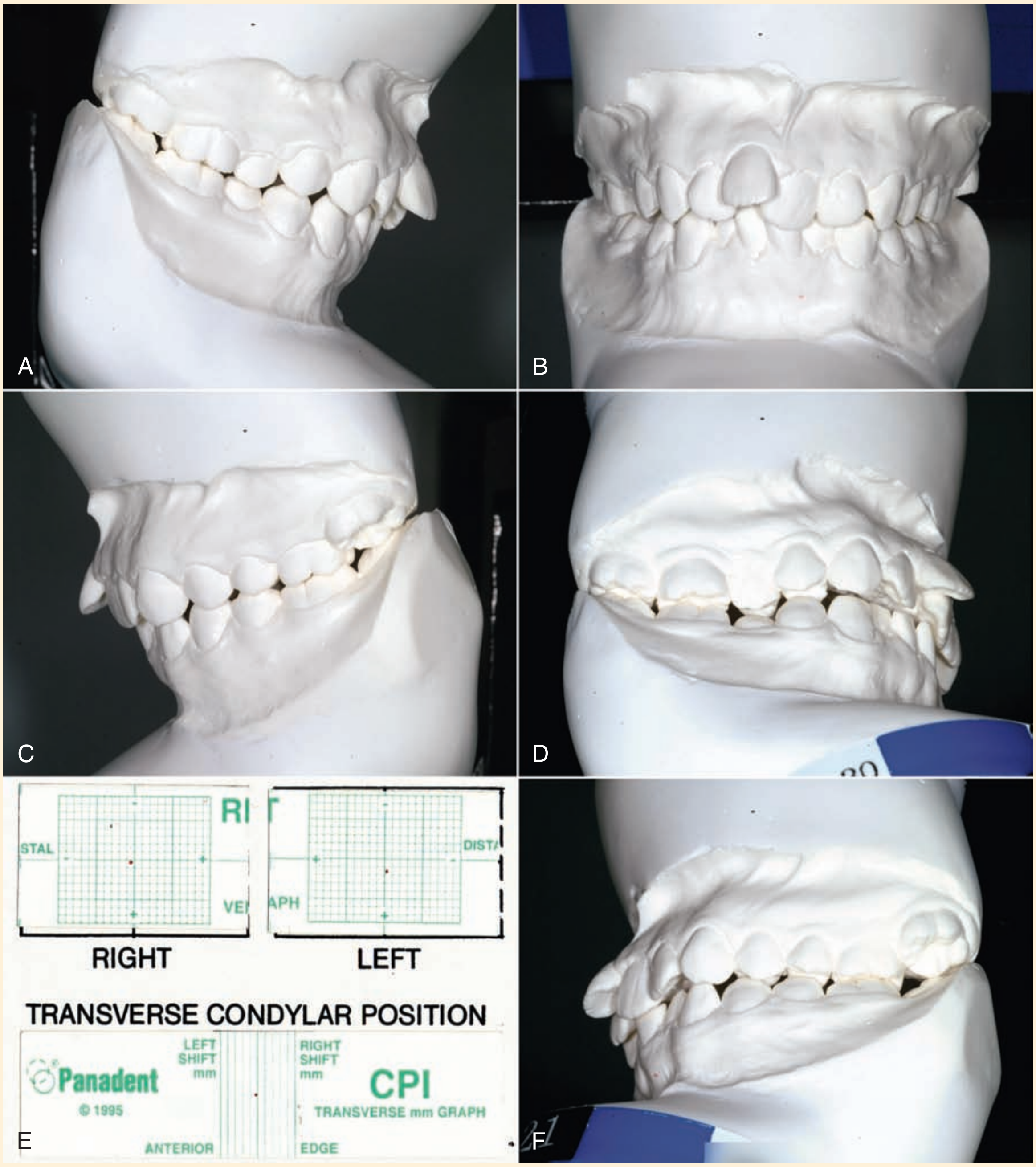

FIGURE 7-12 A–F, Initial models mounted in the musculoskeletal position (CR) and CPI data revealing vertical discrepancy on the left.

CASE STUDY 7-1

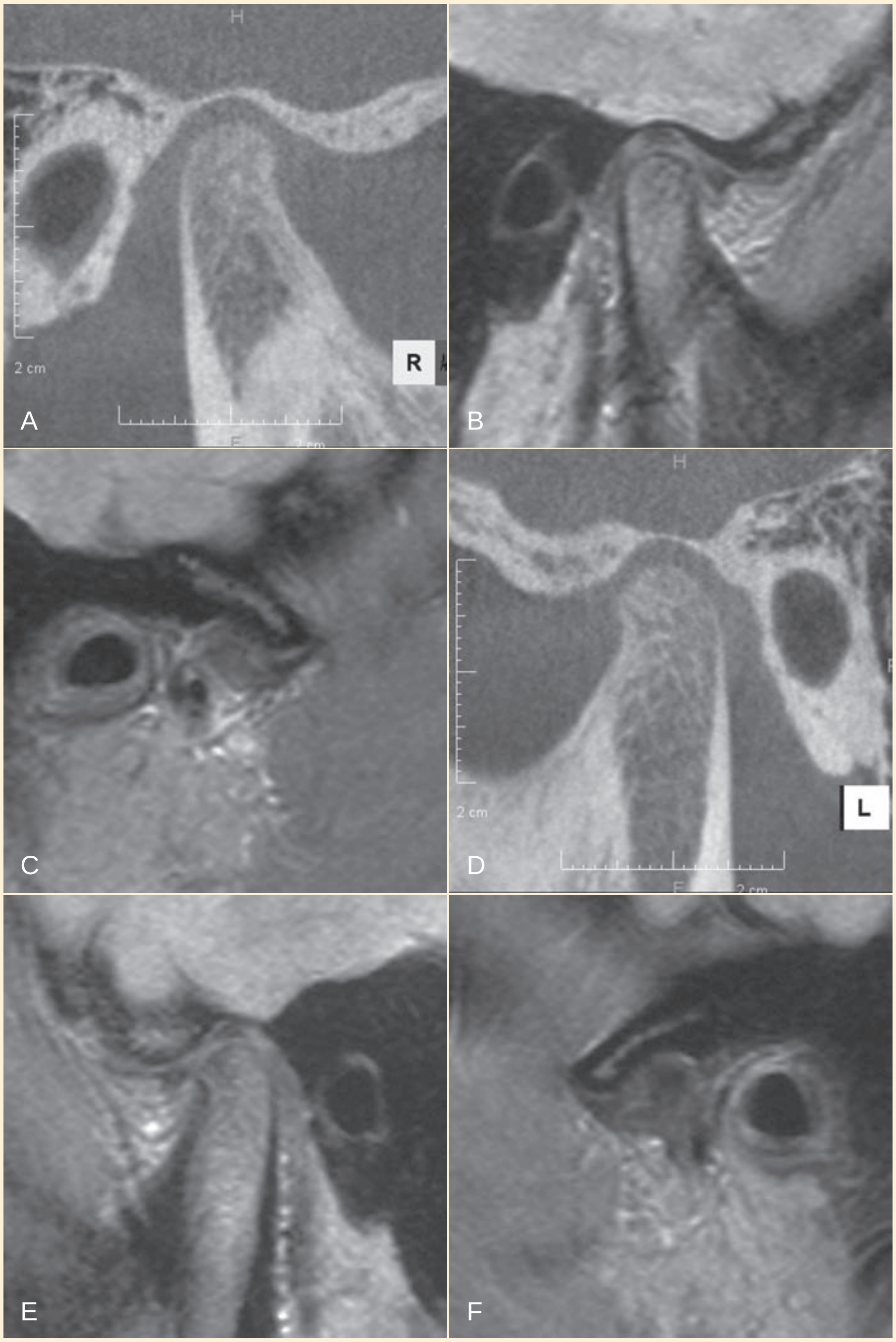

FIGURE 7-13 **A–L,** Initial cone beam computed tomography and magnetic resonance images of the joints. Note the laterally shifted discs on both sides and the some lateral pole remodeling of condyles.

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CASE STUDY 7-1

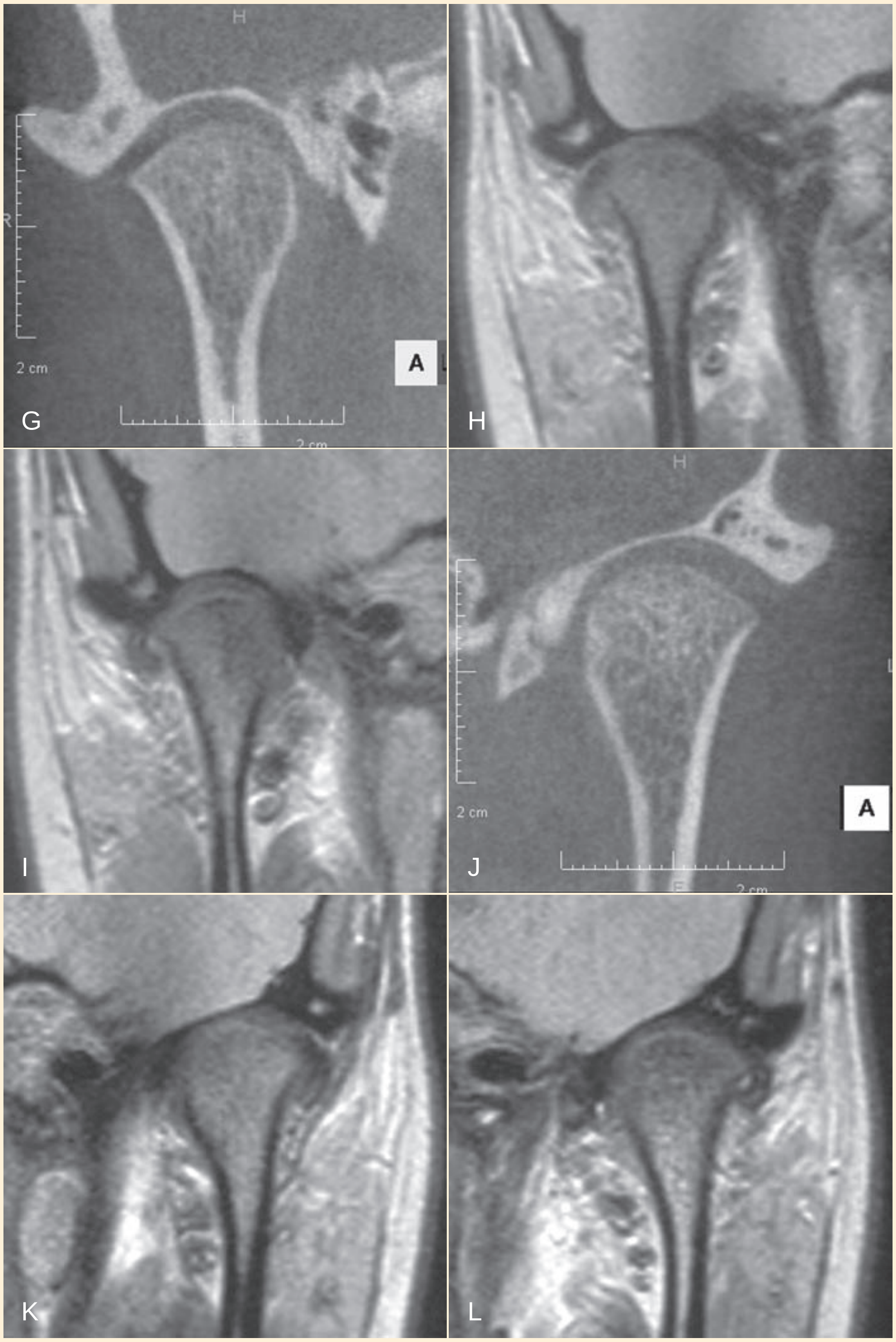

FIGURE 7-13, cont'd

CASE STUDY 7-1

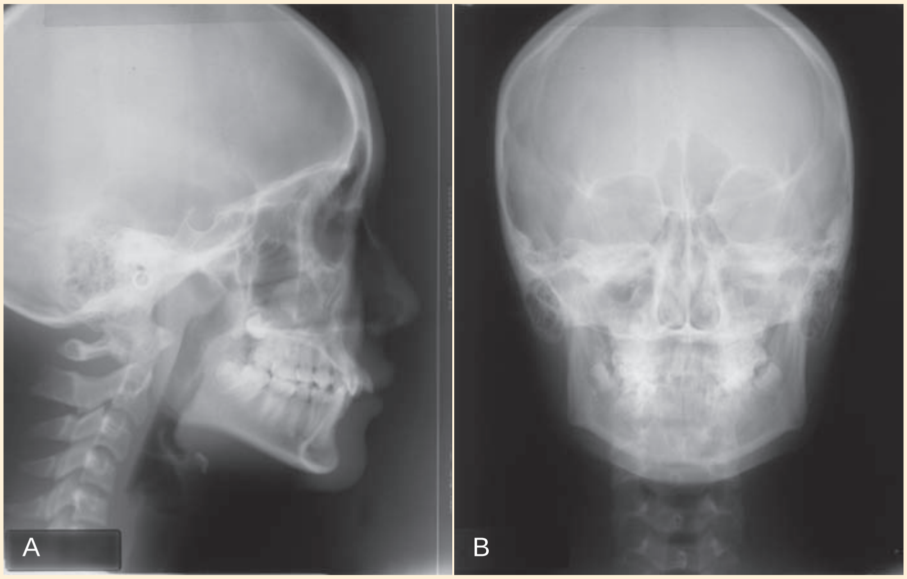

FIGURE 7-14 **A, B,** Initial posteroanterior and lateral cephalograms.

the appliance at night, she noted the bite shift seemed more predominant when she woke up in the morning. She reported that wearing the appliance maintained a more comfortable jaw position. At that time, the patient was then asked to wear the appliance more during the day, especially if this promoted more comfort. She began wearing the appliance for 12 hours on school days and for 24 hours on weekends. The more she wore the appliance, the fewer symptoms she experienced. Several attempts to reduce the use of the appliance reinitiated the symptoms, especially the right TMJ clicking (Figure 7-15).

It was determined that the orthopedic instability was a significant contributor to the TMD symptoms. After 3 months of a symptom-free period with the appliance in the musculoskeletally stable position, the patient's casts were remounted on an articulator and the discrepancy between the stable joint position and the initial tooth contacts during closure was noted (Figures 7-16, 7-17, and 7-18). The posterior teeth were removed from the lower casts to allow closure of the vertical dimension, to better evaluate the relationship of the anterior teeth in the musculoskeletally stable position (Figure 7-19). From this evaluation, along with VTO, (Figures 7-20 and 7-21) an orthodontic treatment plan was developed to establish a sound intercuspal position in the musculoskeletally stable joint of the condyles.

The final result of the orthodontic treatment is depicted in Figures 7-22, 7-23, 7-24, 7-25, and 7-26 at age 16 years 5 months. When observing the final aesthetics, the chin and upper lip position were noted to be improved, while facial muscle strain decreased and therefore muscles appeared less tight. Overall jaw function was also restored to a normal range in various aspects. The final cone beam CT and MRI images reveal that a positive bony change was achieved on both sides at the lateral aspect of the condyles as they appeared slightly rounder following treatment (Figure 7-27). The orthopedic stability created by the orthodontic therapy resulted in a normal range mouth opening and an elimination of the asymmetric mandible shift. It also created a favorable environment for future mandible growth. Muscle and TMJ palpation at the follow-up visit produced no pain, no clicking, and a normal range of jaw function. The right disc was in a normal position while the left disc appeared to be slightly displaced laterally but without any clinical consequence. The patient reported no TMD symptoms and was pleased with the orthodontic results. In summary, the orthodontic treatment successfully achieved a stable and aesthetic occlusal position in harmony with the musculoskeletally stable position.

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CASE STUDY 7-1

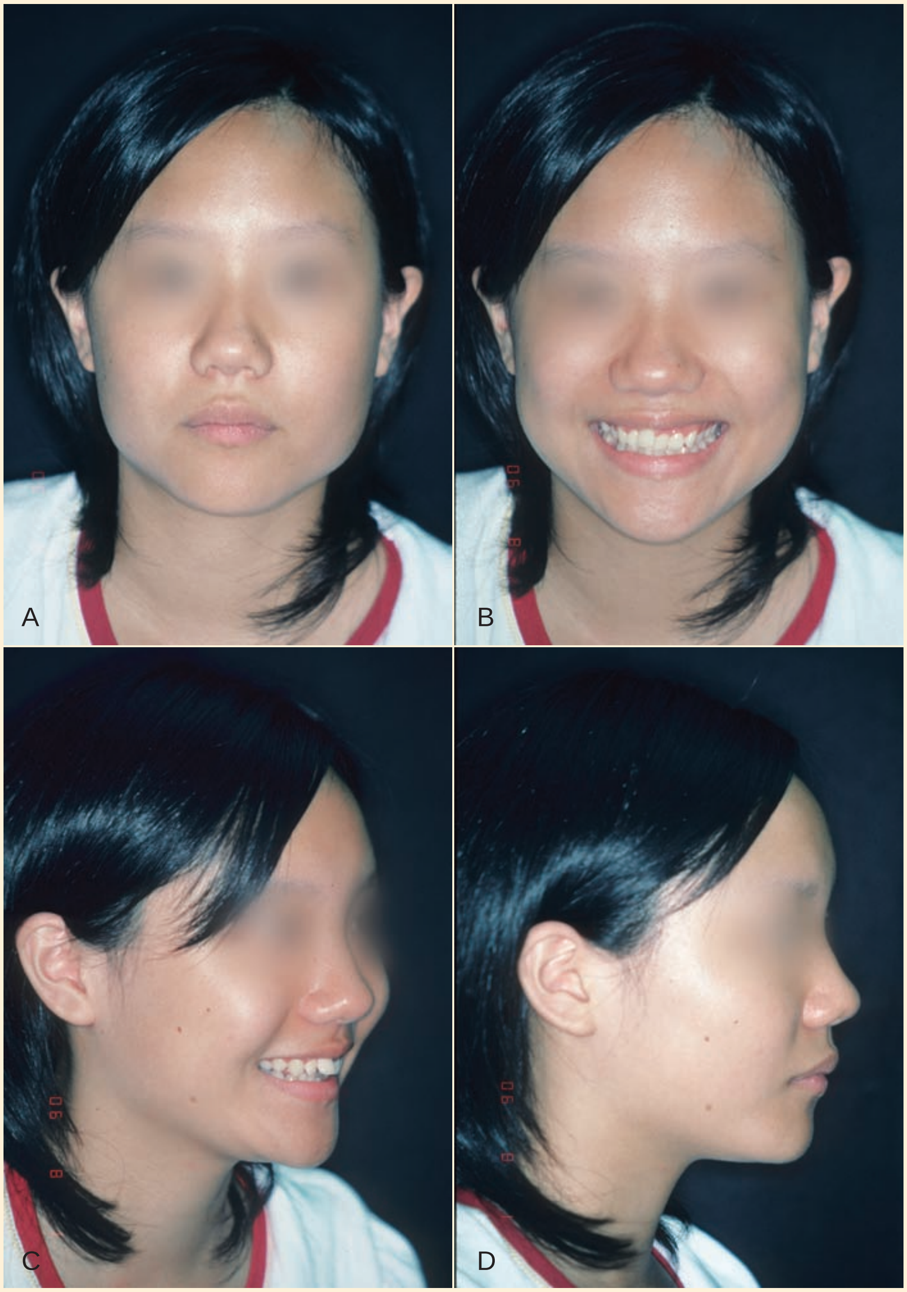

FIGURE 7-15 **A–D,** Facial photographs of the patient at the end of splint therapy. Note the increased appearance of a receded chin and protruded upper lip.

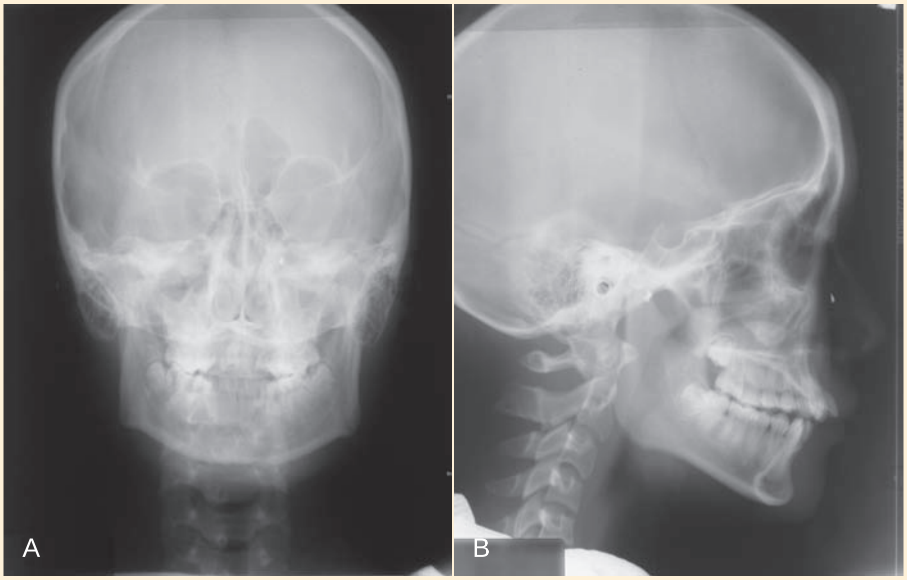

FIGURE 7-16 **A, B,** Posteroanterior and lateral cephalograms of the patient at the end of splint therapy. Note that the mandibular asymmetry to the right was not enhanced by the appliance. As the condyles seated more superiorly in fossae, the mandible retruded, producing an increase in the anterior open bite.

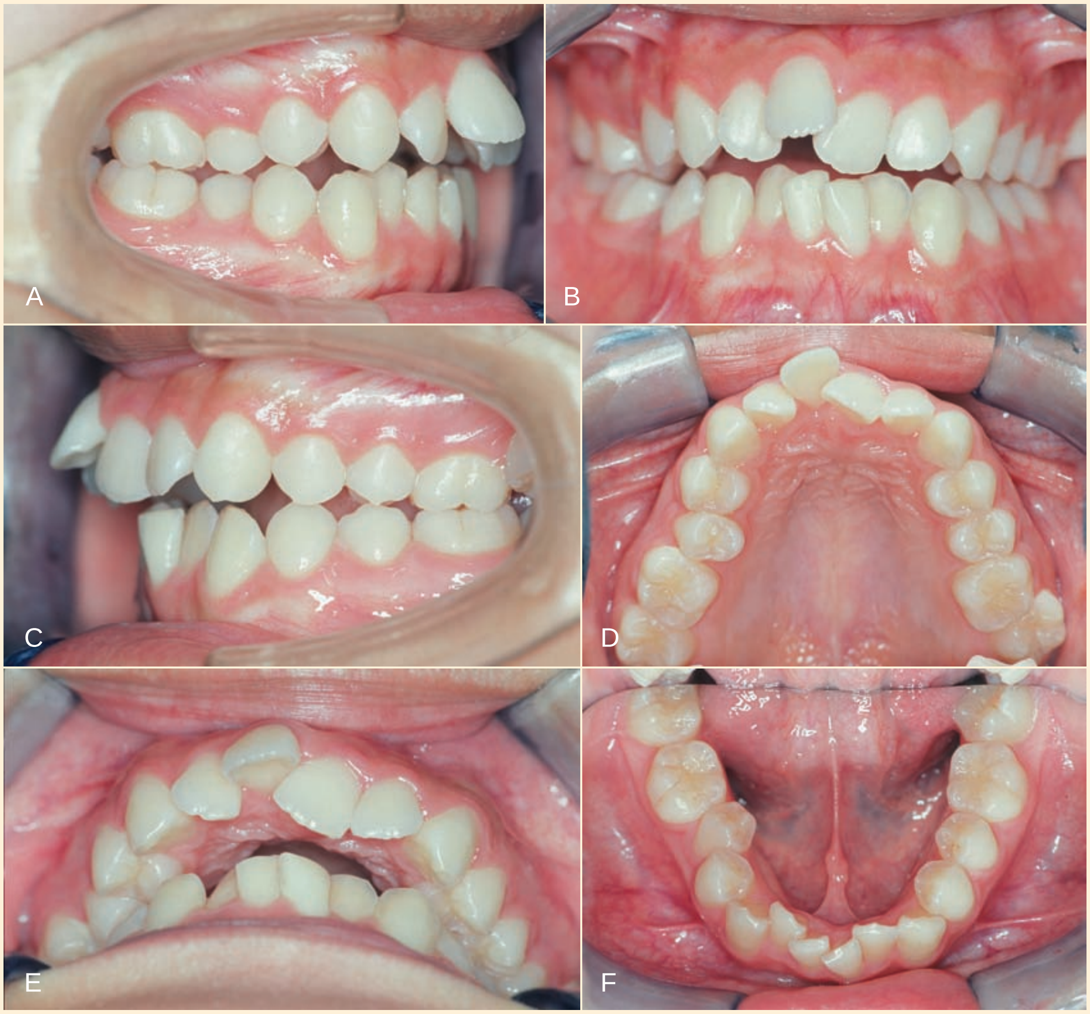

FIGURE 7-17 **A–F,** Intraoral photographs of the patient at the end of splint therapy. While the splint stabilized the jaw position, premature contacts in the molar areas became more evident.

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CASE STUDY 7-1

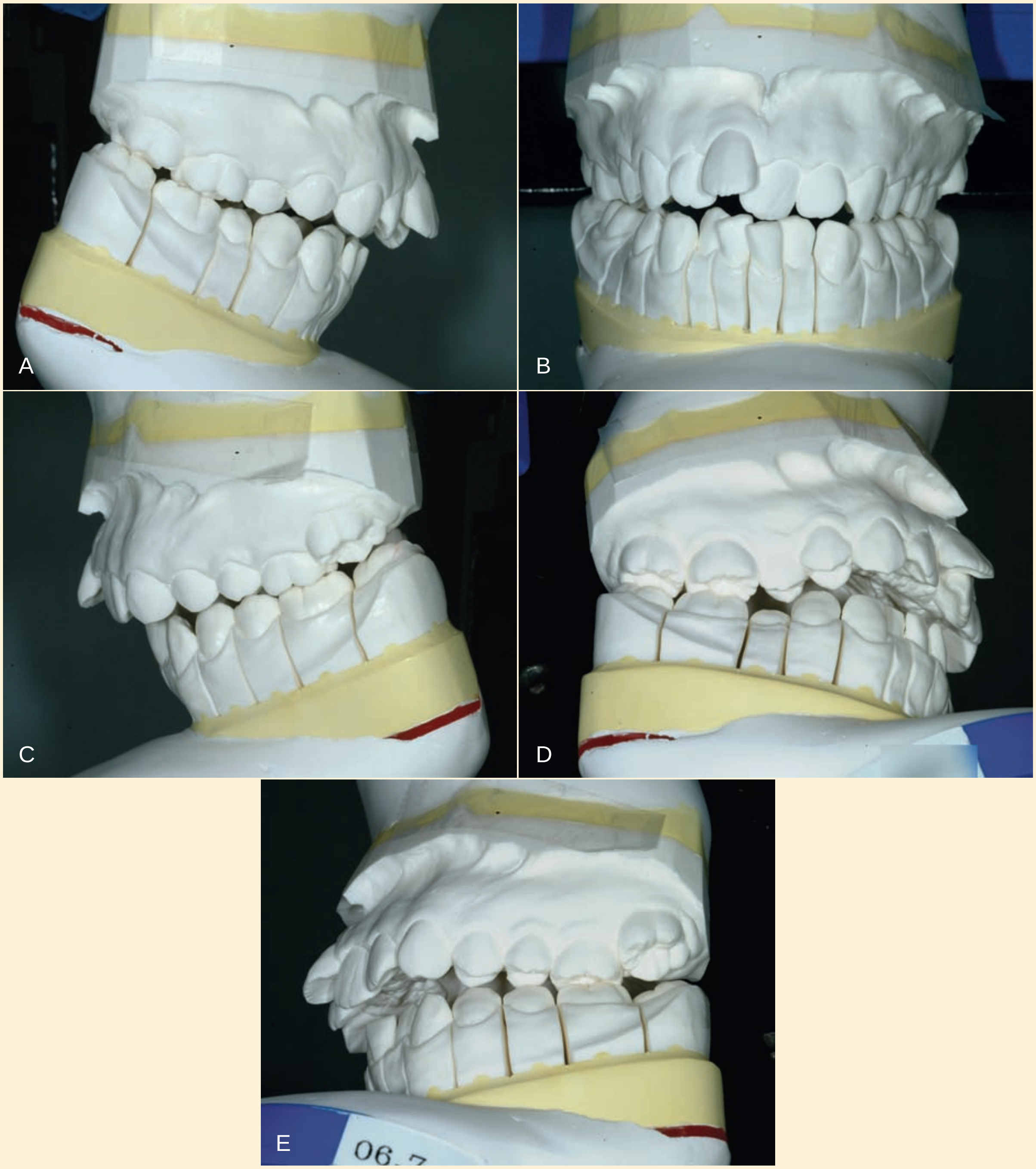

FIGURE 7-18 **A–E,** Photographs of the patient's casts mounted in the musculoskeletally stable position after splint therapy.

CASE STUDY 7-1

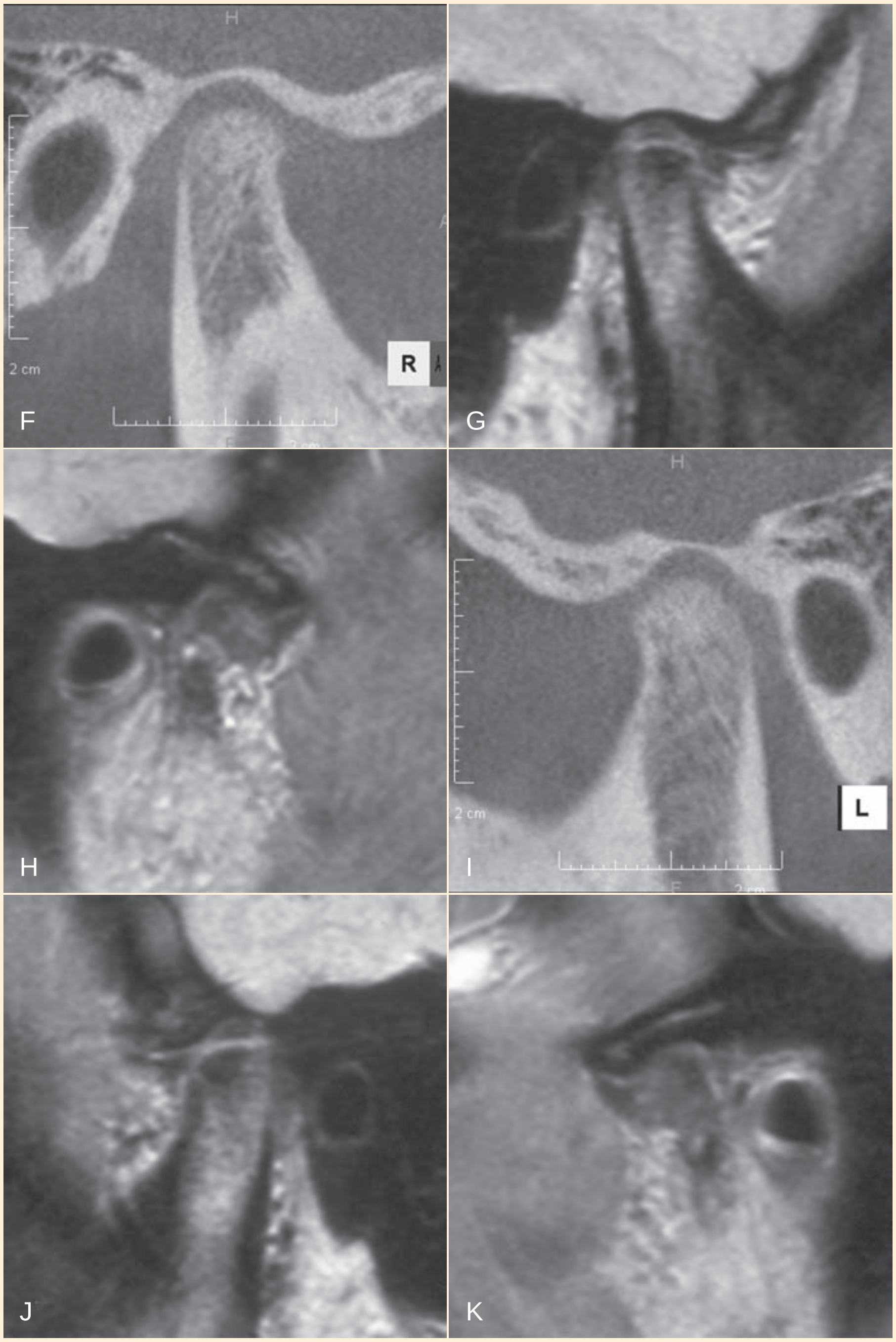

FIGURE 7-18, cont'd **F–Q,** Cone beam computed tomography and magnetic resonance images of the temporomandibular joints after splint therapy. From the coronal views, there appears to be some improvement in lateral disc shift, and change in the morphology of the lateral aspect of the condylar had not progressed.

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CASE STUDY 7-1

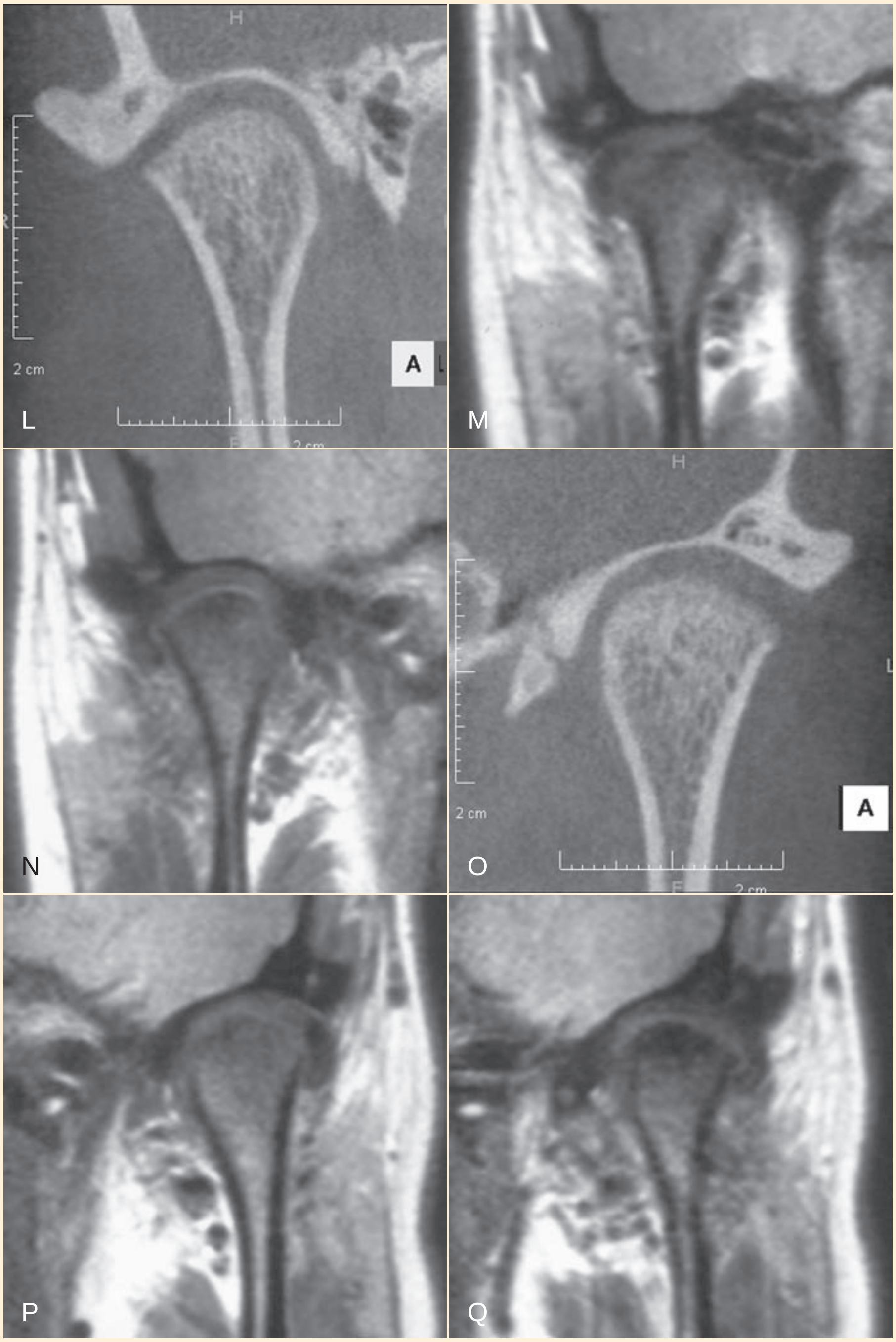

FIGURE 7-18, cont'd

CASE STUDY 7-1

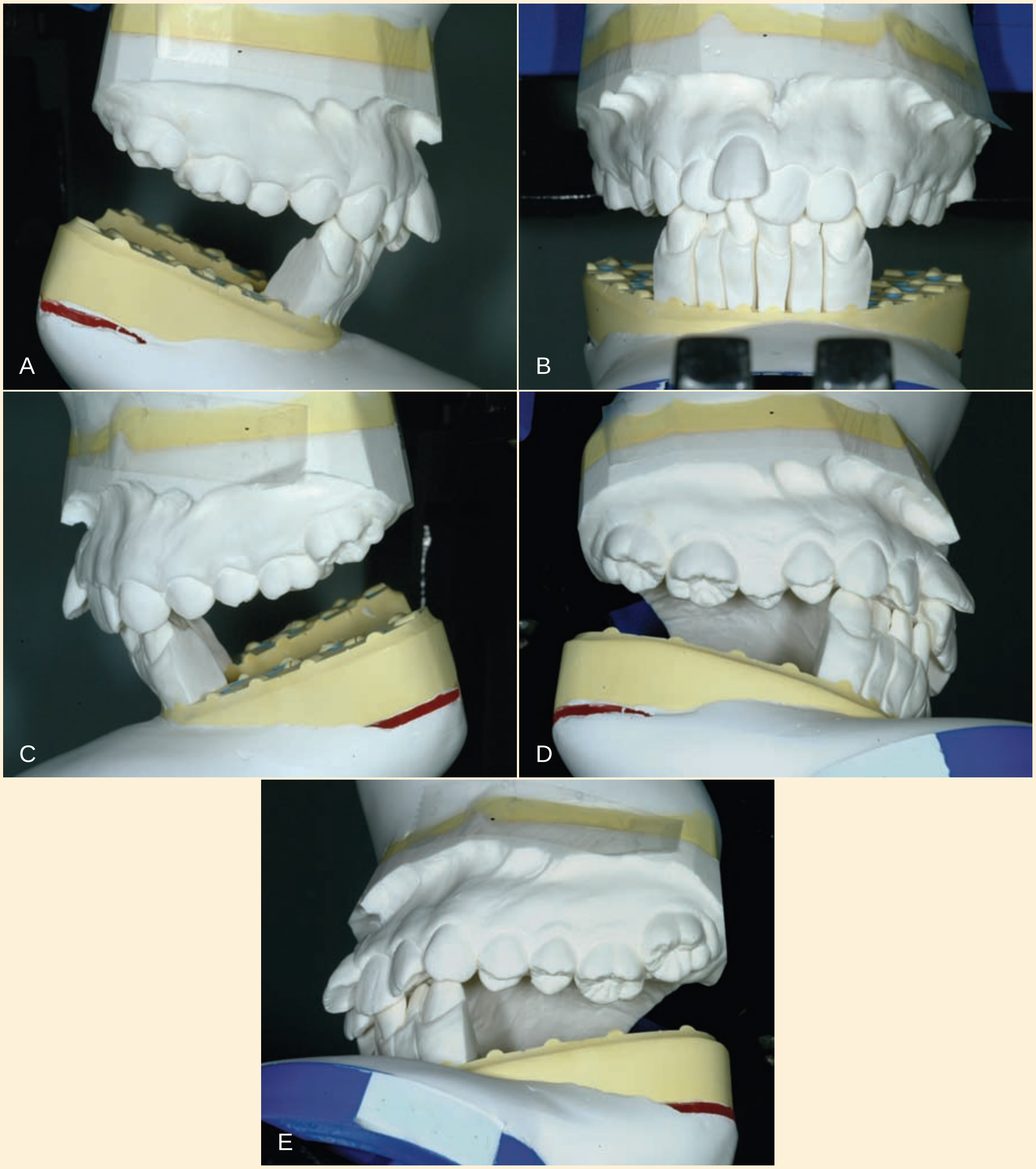

FIGURE 7-19 **A–E,** Three-dimensional check on the mounted pin model. Even once the vertical problems are resolved, a significant amount of overjet will persist. Therefore, care must be taken to prevent any maxillary anchorage loss. Transverse problems are corrected using extraction spaces. In the present case, maxillary second molars were extracted after the ensuring presence of third molars to control vertical dimension and avoid vertical problems caused when jumping the second molars out of crossbite, which would lead to an unstable temporomandibular joint.

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CASE STUDY 7-1

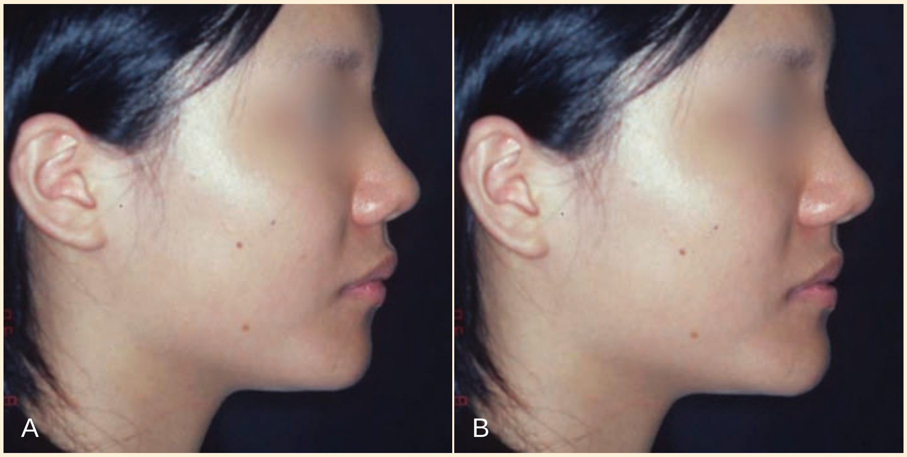

FIGURE 7-20 **A,** Lateral view of the patient at the end of splint therapy. **B,** Prediction of posttreatment profile based on visualized treatment objective.

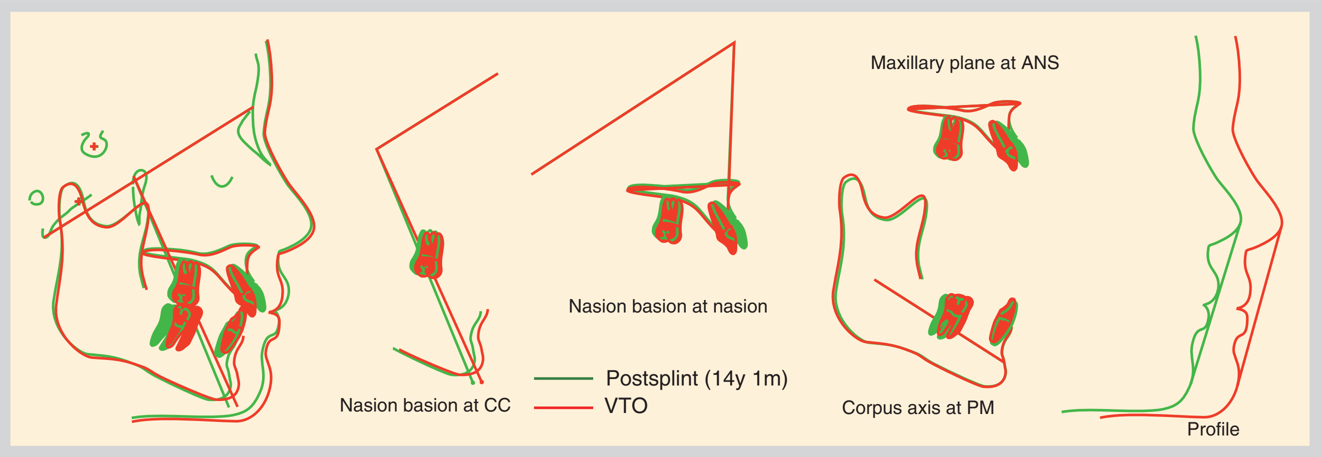

FIGURE 7-21 Superimposition of visualized treatment objective and postsplint tracing. It is important to prevent upper molar anchorage loss with good vertical control. The lower molars will need a significant amount of anchorage with good vertical control. The maxillary incisors will need to be retracted with proper torque control. Only a minimum amount of retraction will be needed for the mandibular incisors.

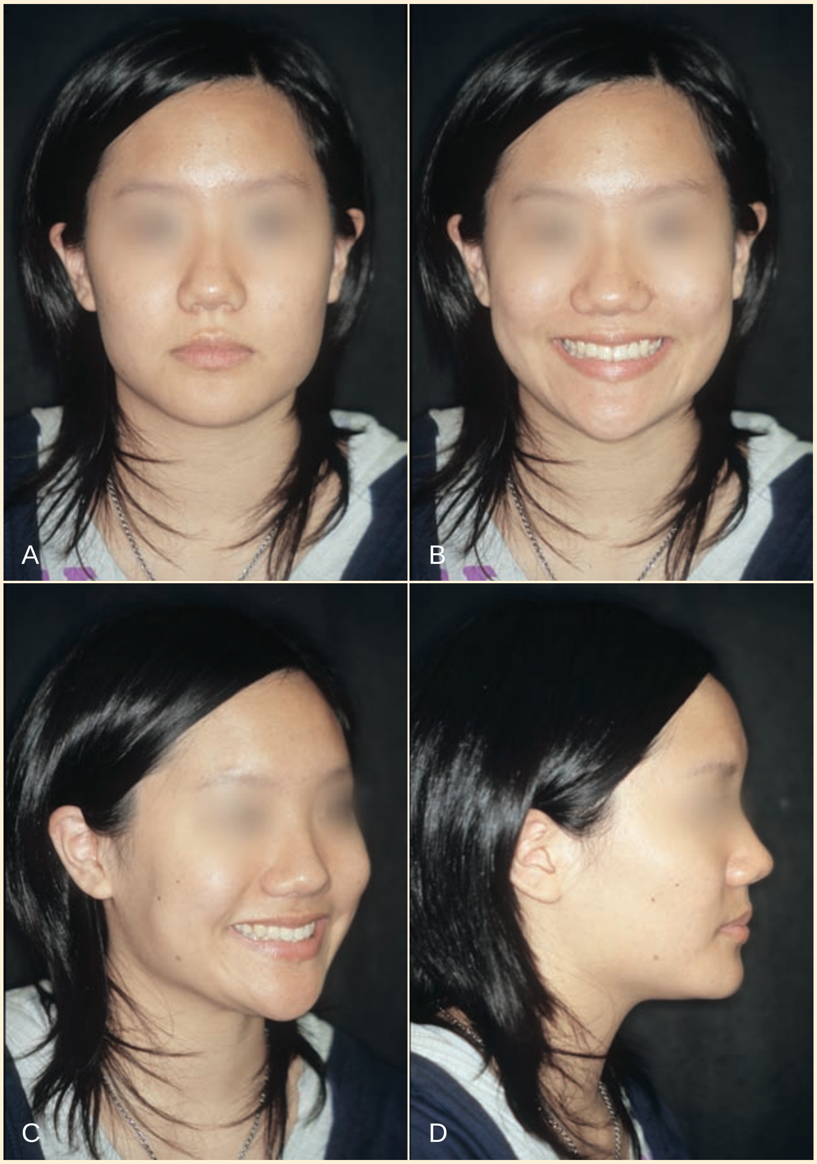

FIGURE 7-22 **A–D,** Facial photographs at the end of active orthodontic treatment (age 16 years 5 months). Note that the masseter muscle hypertrophy has improved.

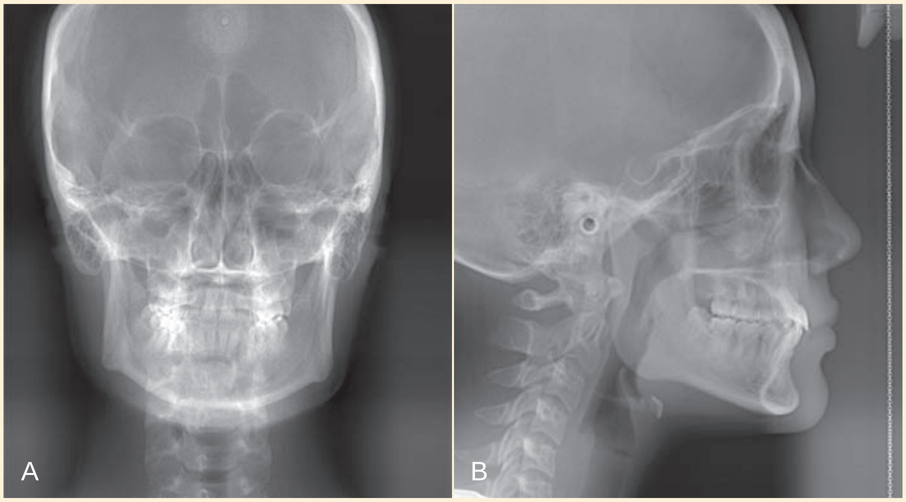

FIGURE 7-23 **A, B,** Posteroanterior and lateral cephalograms at the end of active orthodontic treatment.

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CASE STUDY 7-1

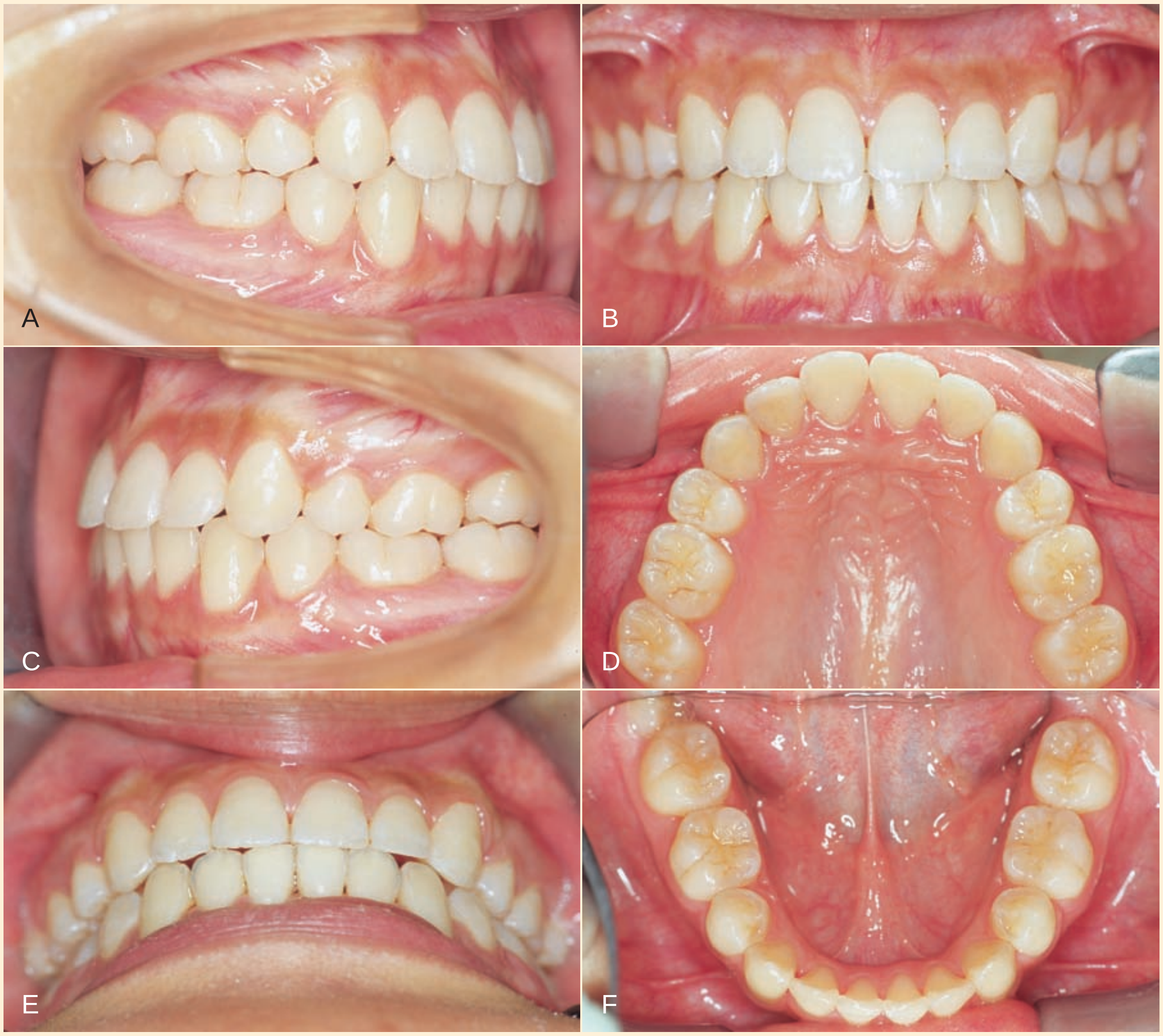

FIGURE 7-24 **A–F,** Intraoral photographs after 2 weeks of gnathologic tooth positioner wear. The tooth positioner allowed the finalization of the intercuspation position of the upper and lower teeth while removing the overcorrections built into the straight wire appliance and maintaining condylar position.

CASE STUDY 7-1

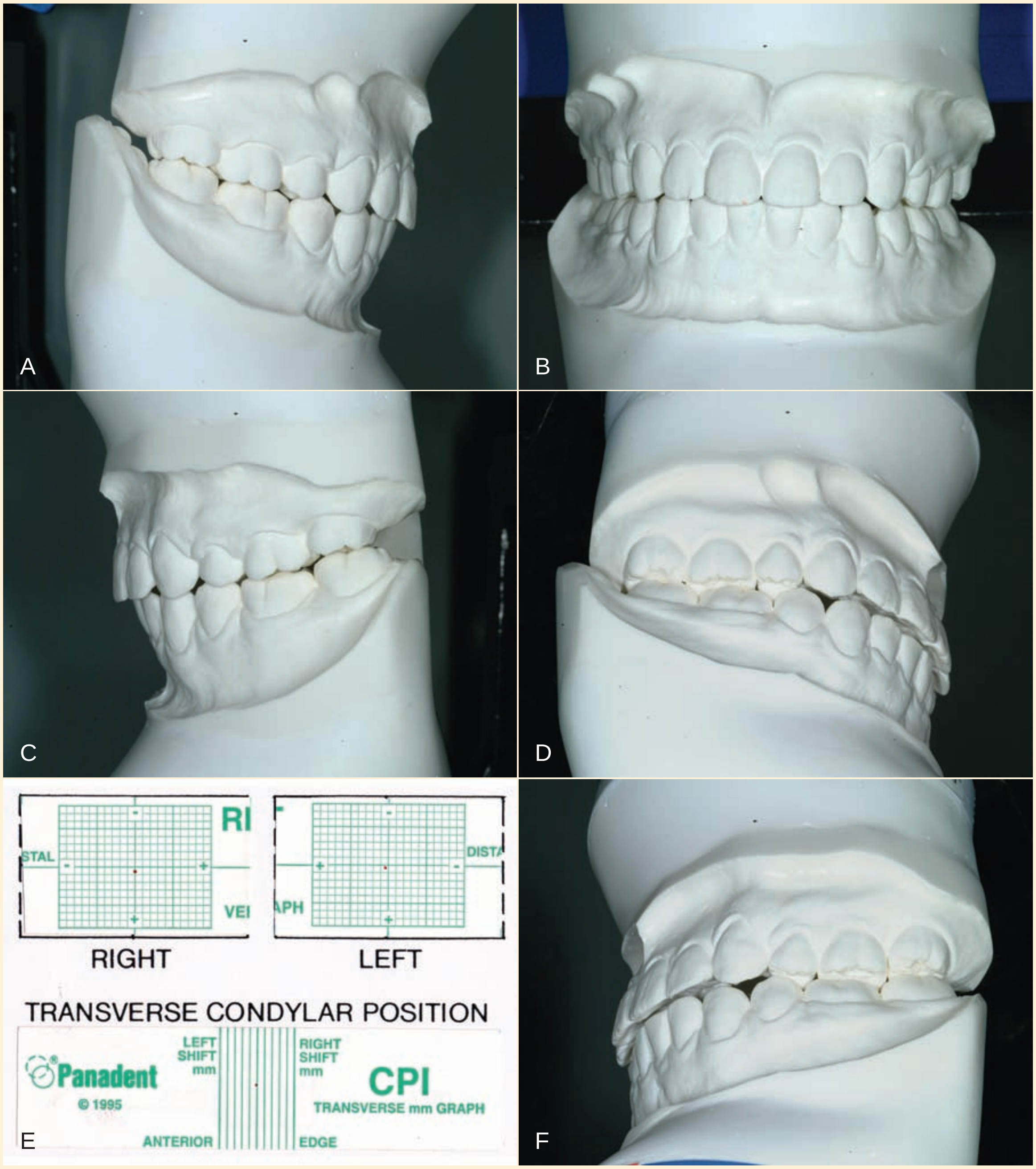

FIGURE 7-25 **A–F,** Final mounted casts in the musculoskeletally stable position at the end of active orthodontic treatment. The discrepancy between the stable joint position and the intercuspal position was very minimal (1 to 1.5 mm).

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CASE STUDY 7-1

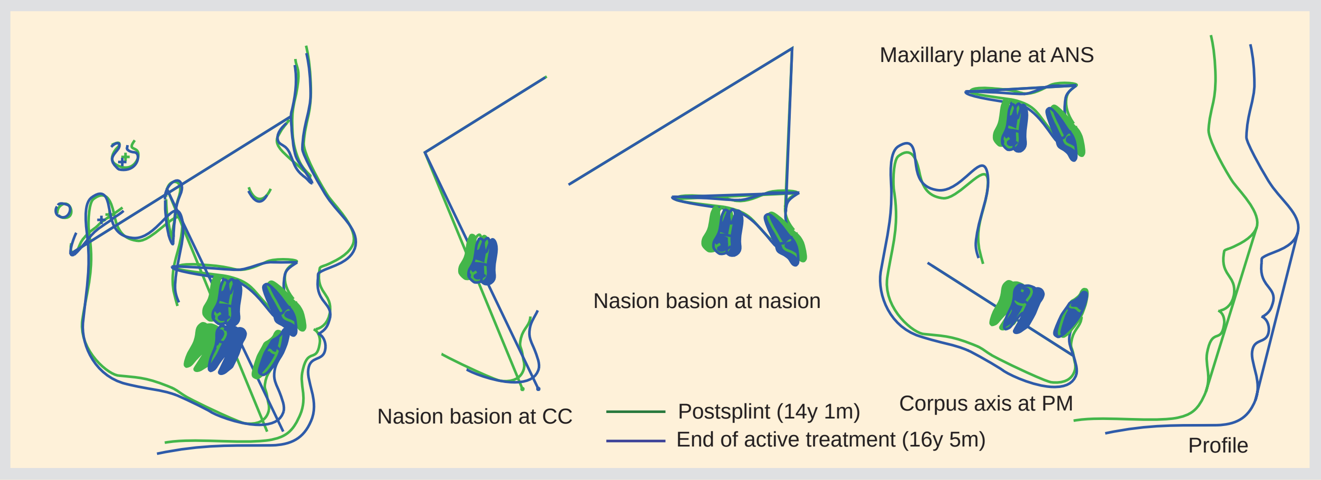

FIGURE 7-26 Superimposition of pretreatment and posttreatment tracings. Successful vertical control during mesial movement of posterior teeth with favorable mandibular growth allowed the facial axis to close and the chin to move forward.

with wax on the model, allowing a good fit. In many patients, this appliance may not need to be worn for very long.

Another appliance that may be considered is the anterior bite plane.[15] This appliance provides only anterior tooth contact and can be useful in reducing symptoms. Because the posterior teeth do not occlude, it may be easier to fabricate and adjust. As soon as the symptoms have resolved, the appliance can be removed and active orthodontic therapy can be resumed.

At that time, the orthodontist needs to consider all the etiologic factors that may be contributing to the TMD, such as emotional stress, trauma, deep sources of pain, and uncontrolled parafunctional activity. The patient should receive a complete history and examination for TMD and be managed appropriately.[15] Orthodontic therapy should not be reinitiated until the TMD symptoms have been properly managed.

In those instances when the TMD symptom is clicking and the orthodontic therapy is effectively moving toward establishing orthopedic stability, the clinician needs to be aware that this symptom is relatively common in the young adult and does not always lead to significant consequence. In fact, one study[24] that observed untreated subjects at age 15 and then again at age 20 found that clicking is very common in this age group and that clicking can come and go unrelated to any major clinical symptoms. Therefore, if the patient reports the onset of a joint sound unrelated to pain and the occlusal condition is being developed in harmony with the stable joint position, patient education regarding the problem may be all that is needed.

On occasion, the clicking joint is associated with significant pain or joint dysfunction, such as catching or locking. When this occurs, active orthodontic therapy should be discontinued and therapy should begin for the specific disorder that has been diagnosed. This might include appliance therapy and/or active physical therapy to the involved joint. The precise treatment for the intracapsular disorder is outside the goals of this chapter, and therefore other texts[15,71] should be pursued for a complete description of therapy.

SUMMARY

The goal of the orthodontist is to develop an aesthetic smile and a functional masticatory system. Although initially esthetics is often considered the most important goal, function eventually becomes far more important in the overall success of treatment. Therefore, the orthodontist must always consider how the orthodontic therapy will affect function. To maximize sound orthopedic function, the occlusal condition must be finalized in harmony with the musculoskeletally stable position of the TMJs. Accomplishing this goal will maximize the success of masticatory function in future years.

CASE STUDY 7-1

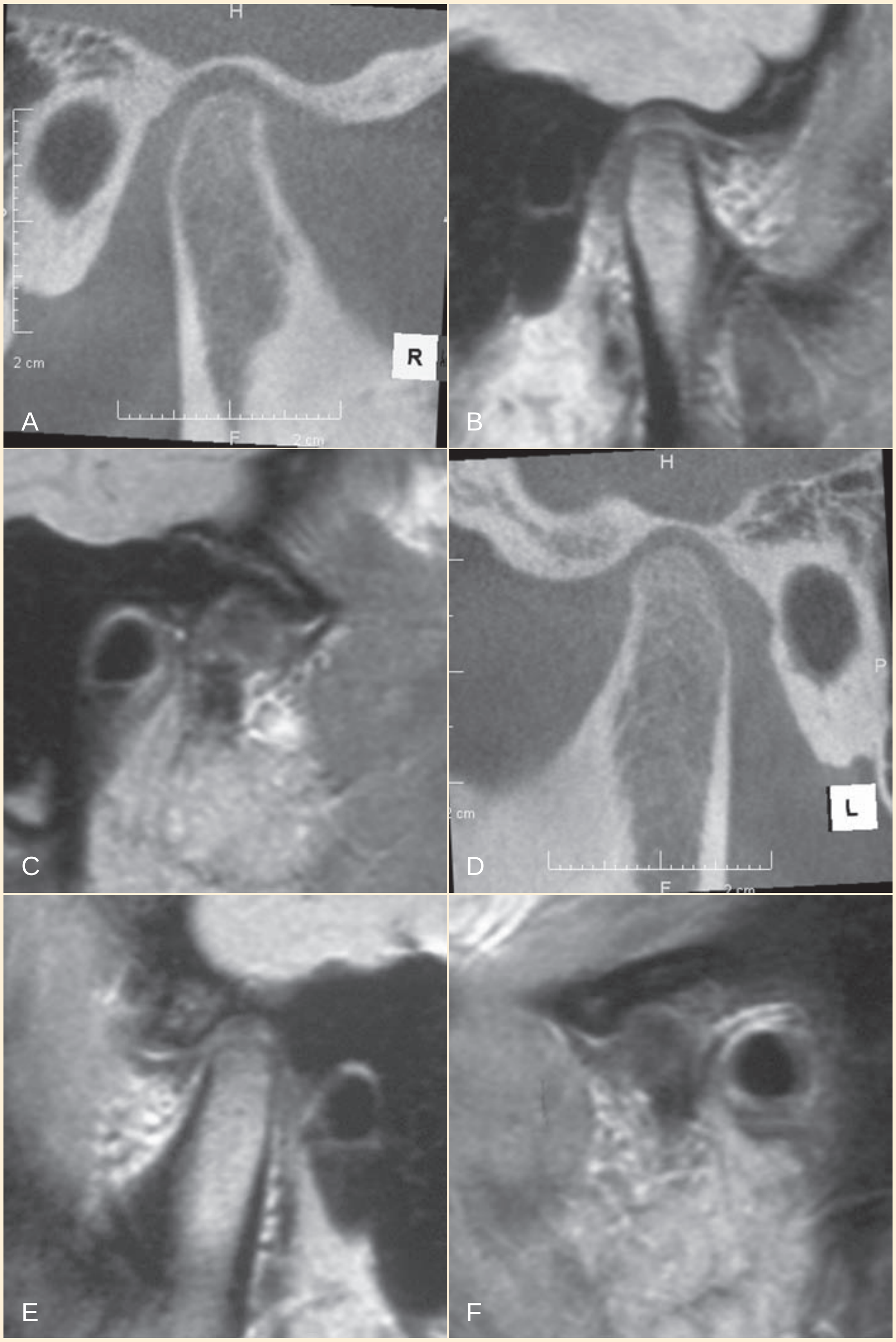

FIGURE 7-27 **A–L,** Cone beam computed tomography and magnetic resonance images of the temporomandibular joints after the end of active orthodontic treatment. The condyles are seated in the fossae with the discs maintaining a stable position (no continued disc displacement). Note the slight improvement in the condylar form and good vertical growth of the condyles.

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CASE STUDY 7-1

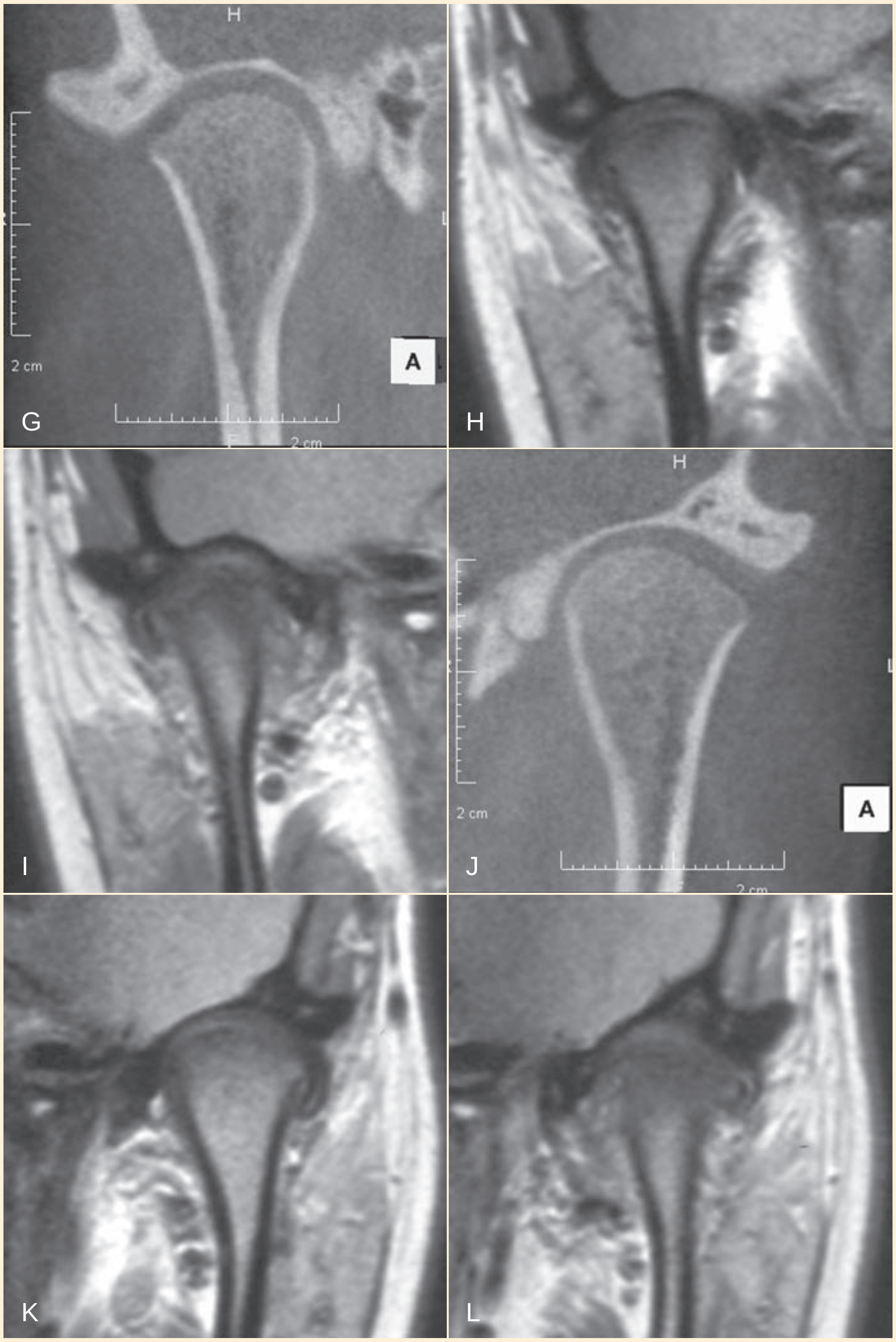

FIGURE 7-27, cont'd

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CHAPTER
8

Craniofacial Growth and Development: Evidence-Based Perspectives

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OUTLINE

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INTRODUCTION

An understanding of the biological principles related to the development, growth, and adaptation of the structures composing the craniofacial complex is essential for attaining competency within the field of orthodontics. Particular emphasis for the advanced practice of orthodontics is placed on the hard tissues comprising the craniofacial regions, the skeletal structures, and the teeth because these are the primary elements that the orthodontist addresses during treatment. Development, growth, and function of other craniofacial structures and tissues, such as muscles, neural tissues, and pharyngeal structures, as well as spaces such as the airway, are also of major interest to orthodontists. However, those elements are important primarily in terms of their influence—structurally, functionally, and developmentally—on the growth, size, and form of the skeletal elements of the face and jaws.

CRANIOFACIAL COMPLEX

The craniofacial complex can be organized according to four anatomic regions, each of which has distinct mechanisms of development and growth, as well as different capacities for adaptation during growth (Figure 8-1).

Structural Units

Desmocranium. The term *desmocranium* refers to the portion of the craniofacial skeleton that arises from a membrane of combined mesodermal and neural crest

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origin, the *ectomeninx*, which surrounds the proximal end of the notochord very early in development. As the brain develops and expands in utero, the desmocranium develops initially as a single fibrous membrane covering of the brain that eventually will give rise to the bones of the cranial vault and fibrous joints, or sutures, as well as the dura mater over the brain and the periosteum overlying the bones of the cranial vault. In fact, in the absence of a brain, as with anencephaly, the desmocranial bones will fail to develop at all. Because the skeletal derivatives of the desmocranium have exclusively a membranous precursor, initial morphogenesis and subsequent bone growth take place completely via intramembranous ossification.

Chondrocranium. The *chondrocranium* forms initially as part of the embryonic anlagen of primary cartilage that will become the cranial base. Like the desmocranium, the chondrocranium is also a derivative embryologically of the ectomeninx. However, the chondrocranium is significantly less dependent on the presence of the brain for its initial formation and subsequent development. Growth associated with the derivative bones of the cranial base occurs by means of endochondral ossification.

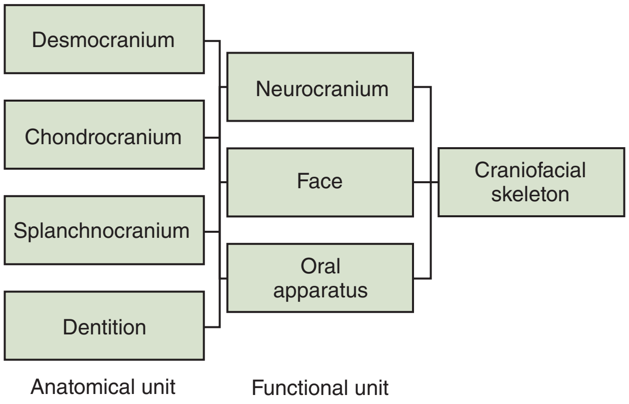


FIGURE 8-1 Schematic of organization of the craniofacial skeleton into anatomic regions and overlapping functional regions.

Splanchnocranium. The *splanchnocranium* (also referred to as the *viscerocranium*) is composed of all those elements of the craniofacial complex that are derived from the first branchial arch and thus are of neural crest origin. These elements primarily include all the bones of the midfacial complex and the mandible. Because the skeletal elements derived from the splanchnocranium have no primary cartilaginous precursors, development and growth of its skeletal derivatives take place via intramembranous ossification that is also characterized by the presence of sutures and a specialized form of membrane-derived (secondary) cartilage at the mandibular condyles.

Dentition. The teeth are specialized anatomic components of the craniofacial complex that are composed of unique tissues and undergo unique mechanism of development characterized by the interaction between ectodermal and mesenchymal tissues.

Functional Units

These four anatomic components can then be combined organizationally into three overlapping but very broad functional and regional units comprising the craniofacial complex (Figure 8-2).

Neurocranium. Within the craniofacial complex, the *neurocranium* houses the brain and other elements of the central nervous system. As the brain rests on the cranial base and is covered by the cranial vault, development and growth of the neurocranium is characterized by a combination of membranous (desmocranium) and cartilaginous (chondrocranium) bone growth.

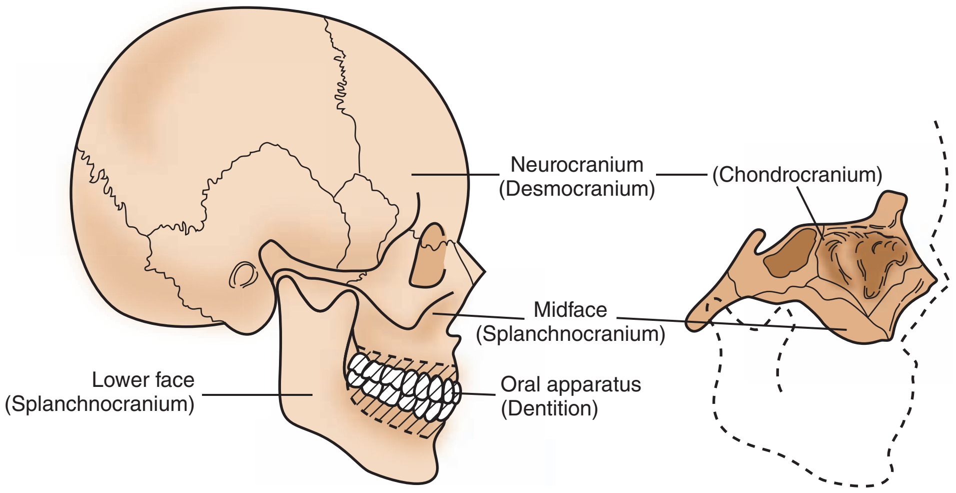


FIGURE 8-2 Major components of the craniofacial skeletal complex.

Face. The upper face and midface are composed externally of the intramembranous bones of the maxillary complex (splanchnocranium). However, like the neurocranium, the face also receives contributions from elements of the chondrocranium. A major contribution from the chondrocranium to the face is the nasal septum, which is a highly active area of cartilaginous growth during fetal and early postnatal development. The lower face, the mandible, develops entirely from the first branchial arch and thus is derived entirely as part of the splanchnocranium. The mandible develops and grows entirely via a specialized form of intramembranous formation of both bone and secondary cartilage.

Oral apparatus. The oral apparatus is composed of the dentition and supporting structures within the upper and lower jaws. Thus, the oral apparatus also is characterized by a unique morphogenesis of the teeth as well as a specialized form of intramembranous bone growth of the alveolar processes of the maxilla and mandible (splanchnocranium). Development and growth of the skeletal structures comprising the oral apparatus are greatly influenced by the muscles of mastication and other soft tissues associated with mastication.

CRANIAL VAULT

Development of the Cranial Vault

At 7 weeks gestation, the developing brain is prominent within the cephalic region and is covered by the dense desmocranial membrane, which is a derivative of the embryonic ectomeninx. By 8 weeks gestation, initial blastemas of bone become apparent within the middle layer of the desmocranial membrane, first for the frontal bone and the squamous temporal bone, and subsequently for the parietal bones and squamous portion of the occipital bone (Figure 8-3). Over the ensuing 4 weeks, these condensations of bone steadily increase in size by radial expansion of newly differentiated skeletal tissue within the desmocranial membrane. As the development of new bone exceeds the rate of growth of the brain, the peripheral bone fronts become located closer and closer to each other, until they approximate each other as single-thickness plates of flat bones by about 12 weeks gestation. At this point, the intervening fibrous tissue becomes highly cellular, and fibrous articulations, or *sutures,* are formed between the individual bone elements.

Development and growth of the cranial vault bones represent a specialized form of intramembranous ossification that begins prenatally as blastemas of bone tissue that arise de novo within the middle layer of the desmocranial membrane covering of the brain. Once the skeletal elements become located close to each other, their fibrous connections become reorganized with the periosteum and the dura mater derived from the outer and inner layers of the desmocranial membrane, respectively, extending into the sutural articulations. The sutures then continue to support growth of the cranial vault through another specialized form of intramembranous osteogenesis similar to periosteal bone formation.[1–5]

Mechanisms of Suture Growth

Sutural bone growth can best be considered as a specialized form of intramembranous, periosteal bone growth. Once formed, the bones of the cranial vault are enveloped, like all bones, in a skeletogenic membrane. On the external surface, this membrane is the periosteum. On the intracranial surface the membrane is the dura mater, which is also derived from the embryonic ectomeninx and also is skeletogenic. Viewed in cross-section, the outer fibrous layer of periosteum (uniting layer) spans

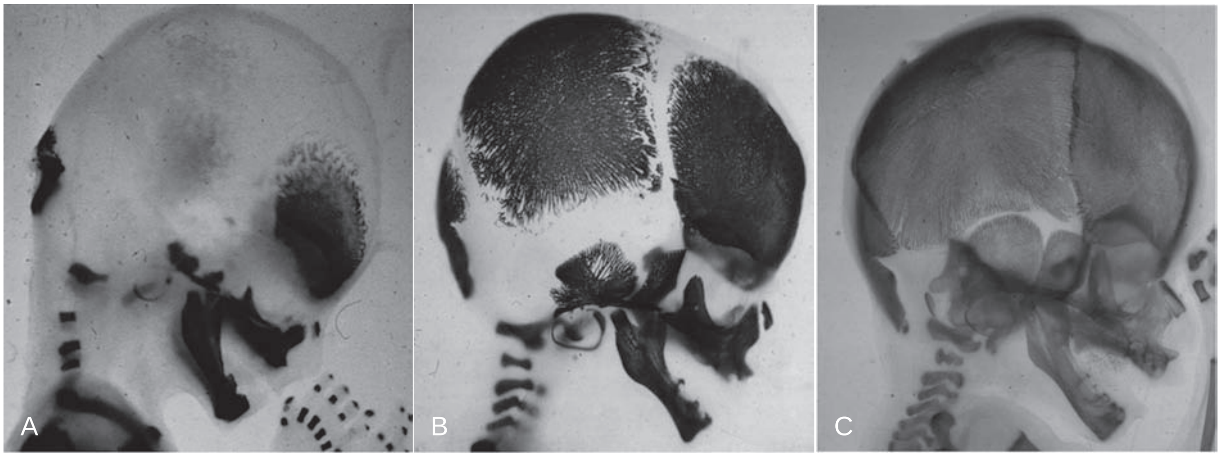


FIGURE 8-3 Cleared and stained human fetuses indicating craniofacial skeletal structures at approximately 8 weeks gestation **(A),** 15 weeks gestation **(B),** and 18 weeks gestation **(C).**

over the cranial suture and provides structural support to the suture and its two or more skeletal elements. The inner, osteogenic layer of periosteum and dura reflects into the space between the two cranial vault bones and provides a source of new osteogenic cells (Figure 8-4). As the bones of the cranial vault become separated due to expansion of the brain and intracranial contents, the osteogenic cells form skeletal tissue and thus provide a mechanism for maintaining relatively close contact through the intervening suture (Figure 8-5).

The molecular basis of osteogenesis at sutural bone fronts is becoming clearer, and it now appears that the dura mater may play a role equal to or even greater than the periosteum with respect to growth of the sutures of the cranial vault. Studies have shown that the secretion of soluble factors by the dura mater in response to growth signals from the expanding, underlying brain is essential for normal cranial suture morphogenesis, as well as for the maintenance of cranial sutures as patent bone growth sites through complex tissue interactions and feedback between dura mater, bone fronts, and sutures (see Opperman and co-workers[6] for a comprehensive review). Both sutures and the dura mater also contain growth factors, such as several members of the family of transforming growth factor beta (Tgf-β1, Tgf-β2, Tgf-β3), bone morphogenetic protein (Bmp2, Bmp7), fibroblast growth factor 4 (Fgf4), insulin-like growth factor 1 (Igf-1), and sonic hedgehog (Shh)[6–9] (Figure 8-6). Removal of the dura mater and the addition of Tgf-β2 and Fgf4 and removal of Tgf-β3 activity induce

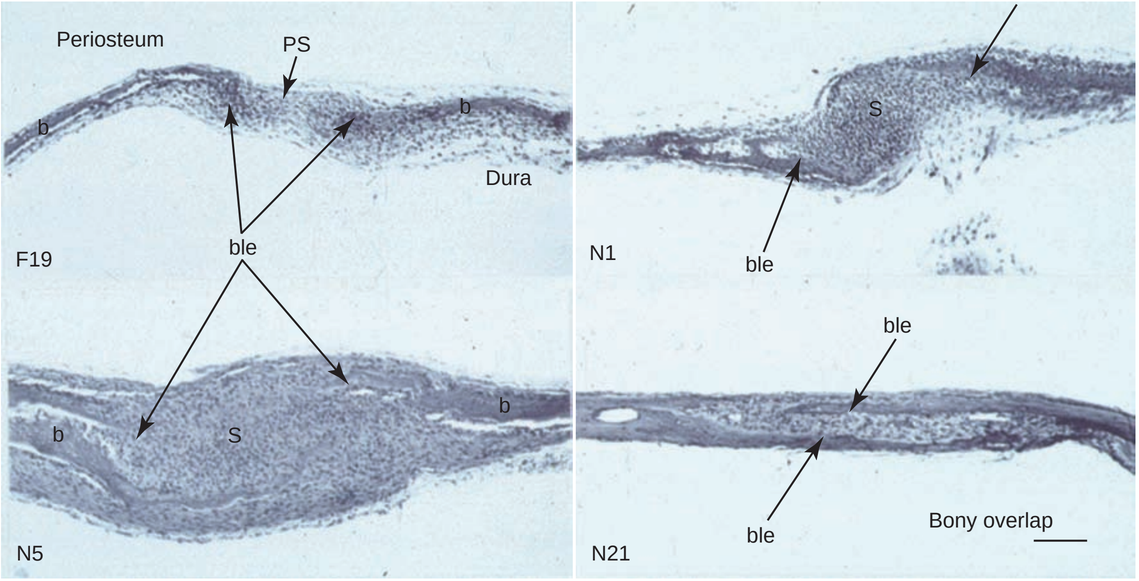


FIGURE 8-4 Photomicrographs of hematoxylin and eosin–stained histologic sections through the coronal suture of normal rats at embryonic day 19 and postnatal days 1, 5, and 21. Bone (*b*) bone leading edge (*ble*) presumptive suture mesenchyme (*ps*) suture (*s*). *(From Opperman et al.[6])*

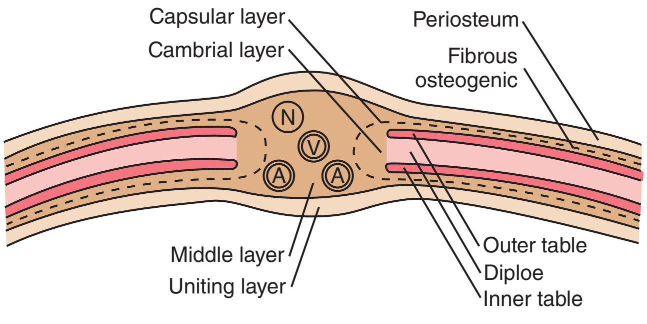


FIGURE 8-5 Schematic representation indicating the relationship between the periosteum and dura mater as a mechanism for a specialized of intramembranous growth within the sutures of cranial vault bones. *(Adapted from Pritchard et al.[1])*

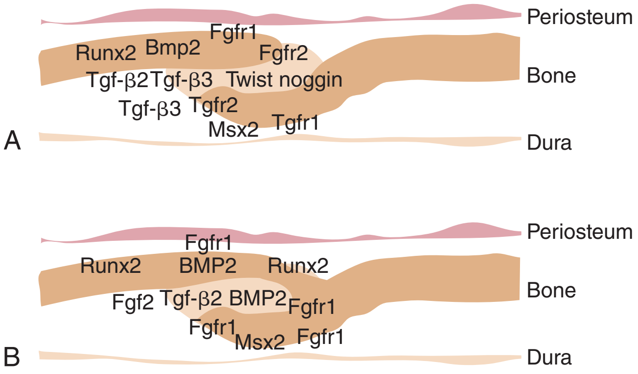


FIGURE 8-6 Distribution of growth factors and transcription factors active during suture growth **(A)** and suture synostosis **(B).** *(From Opperman et al.[6])*

premature cranial suture fusion.[10,11] Overexpression of transcription factors Runx2 and Msx2 and haploinsufficiency of Twist[12] and Noggin[13] are also associated with suture obliteration. Genetic analysis of naturally occurring craniosynostosis in humans has shown that mutations of genes for fibroblast growth factor receptors 1, 2, and 3 (*FGFR1*, *FGFR2*, and *FGFR3*) and in *MSX2*[14] and *TWIST*[15,16] genes are also associated with premature suture fusion.

Development and growth of the cranial vault as a whole and development and growth of bone at the sutural articulations are dependent primarily on the expansion of the brain and other intracranial contents.[4,5,17,18] Furthermore, it has been clearly demonstrated that sutures are secondary, compensatory, and adaptive sites of bone growth that normally respond to biomechanical forces. As the brain expands during prenatal development and during the first decade of life postnatally, forces are created within the neurocranium that cause the bones of the cranial vault to expand outward, which tends to separate them from each other at the sutural boundaries (Figure 8-7). Under normal conditions, the cellular and molecular substrate associated with the dura mater, the periosteum, and the suture respond to this biomechanical displacement in the same manner in which periosteum throughout the skeletal system responds—by initiating and maintaining osteogenesis within the sutures to maintain the proximity of the adjoining skeletal structures. When the biological substrate of the suture is abnormal, however, as in the case of many genetic syndromes such as Crouzon syndrome, Apert syndrome, and Jackson-Weiss syndrome, for example, premature craniosynostosis may result.[19] The opposite condition, reduced suture growth and prolonged patency, as seen in cleidocranial dysostosis, may occur with abnormalities associated with growth factors necessary for normal suture fusion.

Postnatal Growth of the Cranial Vault

Because of the very precocious nature of brain development in humans prenatally and at birth, the cranial vault is disproportionately large relative to the rest of the face and body. At birth, the cranial vault is initially characterized by the presence of all of the cranial vault bones. At that time, all the major sutural fibrous articulations between the bones of the cranial vault are present, including the metopic suture between the right and left frontal bone. In addition, there typically are four larger remnants, known as *fontanels*, of the desmocranial membrane in areas where the pace of bone growth has not been sufficient to approximate the bones of the cranial vault to form a suture (Figure 8-8).

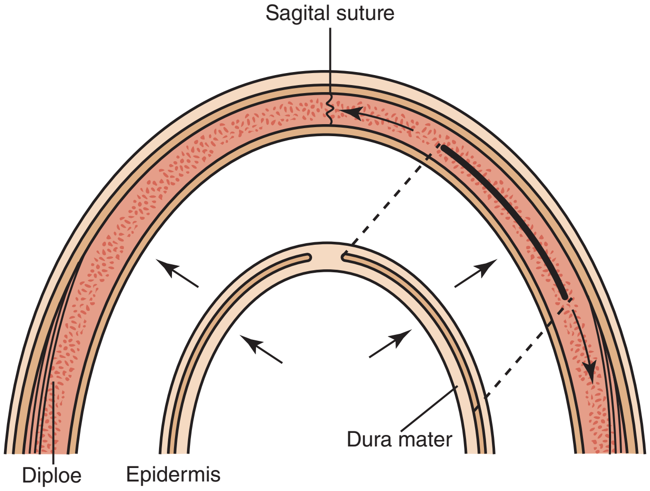


FIGURE 8-7 Schematic diagram indicating the relationship between expansile growth of the brain as a stimulus for compensatory growth of sutures of the cranial vault. *(From Moss.[17])*

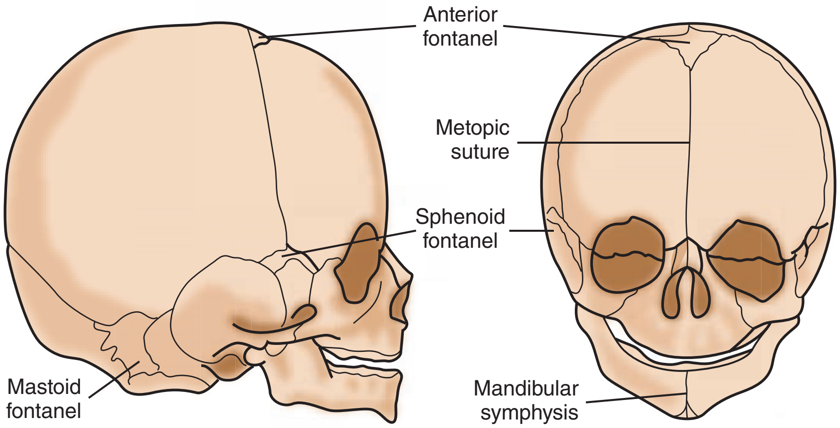


FIGURE 8-8 Lateral and frontal views of the neonate skull indicating the location of sutures and fontanels. *(Adapted from Sicher and DuBrul.[20])*

During the first 24 months after birth, growth of the cranial vault bones proceeds rapidly enough to close the fontanels as each complex of cranial vault bones becomes organized through interlocking sutures. The metopic suture normally begins to fuse to form a single frontal bone at 2 years of age, although the suture may appear to persist for up to 8 years of age. The cranial vault will continue to enlarge primarily as a result of compensatory growth of the sutural bone fronts as brain growth proceeds. By 4 years of age, the brain and the associated cranial vault will have achieved approximately 80% of adult size; by age 10, the brain and cranial vault have attained 95% of their adult size. Throughout this time of very rapid expansion, the remaining sutures of the cranial vault normally remain patent and actively growing to keep pace with the brain as it expands in size.

Osteogenesis at cranial sutural bone fronts may continue for the first two decades of life. However, by the end of the second decade of life, bone growth at cranial sutures has slowed and the potential for growth of cranial sutures has greatly diminished. Also at that time, the sutures will begin the normal process of bony closure, or *synostosis*, when the potential for sutural growth ceases altogether.

All the cranial sutures normally lose the capacity for growth by the end of the second decade of life, and virtually all become synostosed during the life span. Normal suture closure is initiated along the endocranial surface. Initially, this is characterized by bridging of bone across the suture and eventually through remodeling of bone, leading to complete obliteration of the suture. Cessation of growth at cranial sutures typically begins around age 25 for the sagittal suture and may be extended for 2 to 3 additional years for the coronal suture.

Despite the fact that the major cranial sutures stop growing by the third decade of life, some enlargement of the cranial vault overall typically occurs throughout the life span as a result of periosteal growth along the ectocranial surface. Certain specific areas of the cranial vault, such as the glabellar and nuchal regions, may exhibit slightly greater periosteal growth as a secondary sex characteristic in males.

CRANIAL BASE

Development of the Cranial Base

The embryonic ectomeningeal membrane that surrounds the developing brain differentiates in the cranial base region into a number of paired cartilaginous elements to form the embryonic chondrocranium. The first of the cartilage anlagen to form, at about 6 weeks gestation, are the parachordal cartilages, which surround the proximal end of the notochord and give rise to the basioccipital bone. Development of the chondrocranium then progresses rostrally to the otic capsule, which will form the petrous portion of the temporal bone; the postsphenoid, presphenoid, alisphenoid, and orbitosphenoid cartilages of the sphenoid bone; and the nasal capsule and mesethmoid, which will form the ethmoid bone, inferior turbinate, and nasal septum. By 8 weeks gestation, the separate cartilage elements have merged to form a single plate of primary hyaline cartilage, the *basal plate,* extending from the foramen magnum rostrally to the tip of the nasal cavity (Figure 8-9).

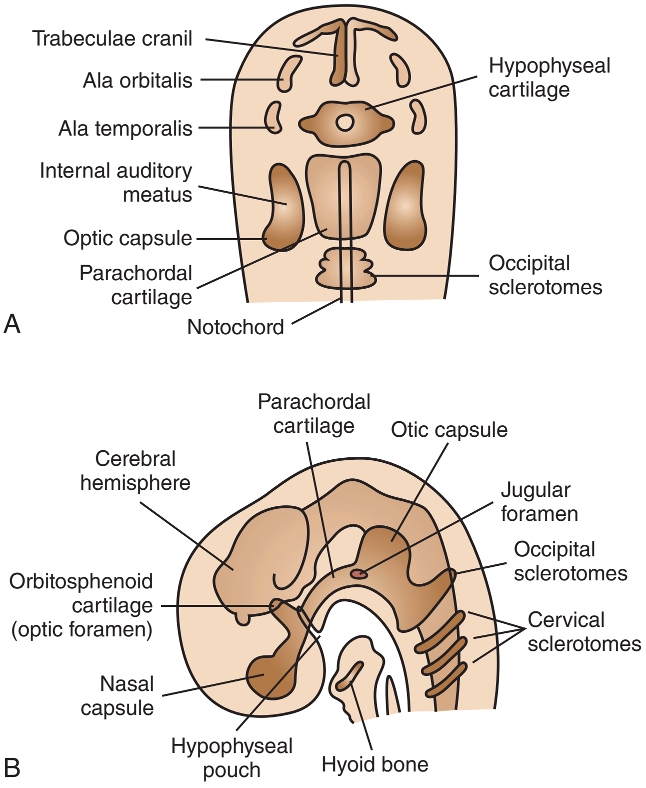


FIGURE 8-9 Schematic representation of the cartilaginous basal plate comprising the embryonic chondrocranium.

More than 110 separate centers of ossification form in the basal plate, beginning in the parachordal cartilages and continuing rostrally through the sphenoid complex around 9 to 16 weeks, to the ethmoid region as late as 36 weeks. As these centers of ossification arise within the chondrocranium, segments of intervening cartilage form *synchondroses* (Figure 8-10). The principal cranial base synchondroses that are most relevant for understanding craniofacial growth are the spheno-occipital synchondrosis, between the body of the sphenoid and the basioccipital bone, and the sphenoethmoidal synchondrosis, between the sphenoid and ethmoid bones. The greater wing of the sphenoid bone, the facial ethmoid, and the squamous portion of the occipital bone develop and grow via intramembranous ossification.

Mechanism of Synchondrosal Growth

Cranial base synchondroses are temporary cartilaginous joints located between bones of endochondral origin

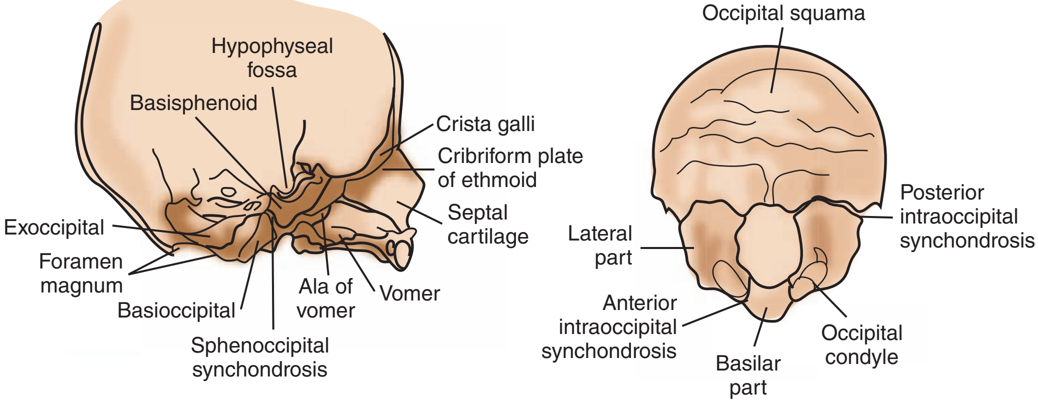


FIGURE 8-10 Drawing of sagittal and basal views of the neonatal skull indicating spheno-occipital synchondrosis and intraoccipital synchondroses. The sphenoethmoidal synchondrosis will arise between the sphenoid and ethmoid bones. *(Adapted from Bosma.[21])*

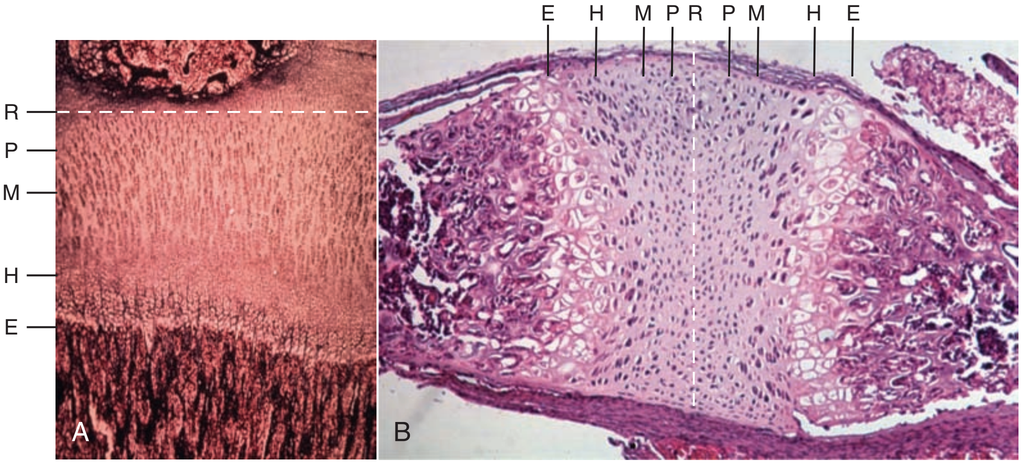


FIGURE 8-11 Histologic comparison between the cartilages within a growing epiphyseal plate **(A)** and cranial base synchondrosis **(B)** (hematoxylin and eosin–stained). *R*, Resting zone (*dashed line*); *P*, proliferating zone; *M*, maturational zone; *H*, hypertrophic zone; *E*, zone of endochondral ossification.

and growth. Synchondroses can best be considered as analogous to the epiphyseal growth plates of long bones. Functionally, both provide a mechanism for rapid endochondral growth of bone in a manner that is capable of overcoming biomechanical loads, thus exhibiting tissue-separating capabilities. Developmentally, cranial base synchondroses and epiphyseal plates of long bones synostose and become obliterated when the skeletal element achieves its mature size and shape. This typically occurs at the end of puberty for epiphyseal growth plates but varies from the end of the juvenile period through the end of puberty for the major cranial base synchondroses.

Cranial base synchondroses and epiphyseal growth plates are both derived from the primary hyaline cartilage that arises as part of the embryonic cartilaginous anlagen. Histomorphologically, both cranial base synchondroses and epiphyseal growth plates are characterized by primary chondrocytes that are distributed into zones that are highly typical for growth plate cartilage (Figure 8-11). However, a major difference between epiphyseal growth plates in long bones and cranial base synchondroses is that synchondroses are “bipolar.” Thus, each cranial base synchondrosis effectively has two back-to-back growth plates with a shared region of newly forming cartilage in the center and bone at each end. Growth plates are “unipolar.”

The primary hyaline cartilage of the cranial base is the same as that found throughout the embryonic cartilaginous anlage that characterizes all the other cartilaginous bones throughout the body. It is well known that growth of tissues derived from the primary embryonic cartilaginous anlagen tends to be relatively resistant to all but very extreme external influences. Growth of cartilage-derived skeletal elements throughout the body tends to be relatively resistant to environmental and other factors, and instead is regulated to a large extent by intrinsic, genetically regulated growth factors and cell-signaling molecules.[22] The same is true for the cranial base synchondroses. However, it is important to note that the growth of both epiphyses and synchondroses can be significantly affected by such epigenetic factors as disease, malnutrition and undernutrition, as well as other conditions that affect production and expression of endocrine factors responsible for bone growth (see Spears and Svoboda[23] for a comprehensive review).

The cartilage cells within both epiphyseal growth plates and cranial base synchondroses are characterized by extensive amounts of extracellular matrix that is secreted by and separates the cartilage cells. This matrix makes the cartilage very dense and strong but also flexible relative to bone and thus better able to absorb mechanical forces without directly affecting the cells and potentially altering growth. Because there are no vessels within cartilage extracellular matrix, all nutrients, growth factors, and cell signaling molecules must diffuse through the matrix to reach the chondrocytes. The matrix thus “buffers” the chondrocytes from extrinsic mechanical forces and many soluble molecules that might provide information about the external environment. As a result, cartilage growth in general and endochondral ossification from primary hyaline cartilage in particular tend to be more rigidly programmed genetically than intramembranous bone growth associated with periosteum, such as occurs in the desmocranium and splanchnocranium.

The dichotomy in the mechanism of growth between bone formed by means of intramembranous ossification and bone derived from endochondral ossification was well delineated in a classic paper by Baume.[24] Baume defined areas of primary cartilaginous growth bone growth as *skeletal growth centers*. Development and growth of the skeletal tissues derived from primary cartilage are significantly more intrinsically regulated and less dependent for their expression on epigenetic factors. In particular, *growth centers* have what has been described as “tissue-separating capabilities,” emphasizing the capacity to grow and expand despite the presence of epigenetic mechanical forces that would seem to be capable of inhibiting or restricting skeletal growth. Thus, epiphyseal and synchondrosal cartilage exhibit the ability to exert tissue-separating force during growth. Because of the virtually identical nature of their origin and developmental processes, the cranial base synchondroses are also generally perceived as *growth centers* that possess tissue-separating capability.

In contrast to a growth center, a *growth site* is an area of skeletal growth that occurs secondarily and grows in compensatory fashion to growth and function in a separate but proximate location. *Growth sites* have no tissue-separating capabilities but rather respond more readily to factors extrinsic to their specific area. Periosteal bone growth associated with muscle function is one obvious example of a *growth site*. Sutural bone growth is another example of a class of *growth sites* because of its association with bones of intramembranous origin and its clear connection to periosteal bone growth.

Postnatal Growth of the Cranial Base

Late prenatal and overall postnatal growth of the cranial base is related directly to growth of the synchondroses. There are three principal growth-related cranial base synchondroses that separate the bones of the cranial base at birth. The intersphenoid synchondrosis, between the presphenoid and basisphenoid, fuses around the time of birth in humans and thus does not contribute to postnatal growth. The sphenoethmoidal synchondrosis, which lies between the sphenoid and the ethmoid bones, is most active with respect to growth of the cranial base through approximately 7 years of age in humans. At that time, the sphenoethmoidal synchondrosis loses its cartilage phenotype and becomes a suture. Once that transition occurs, growth of the anterior cranial base is essentially complete. As a result, the anterior wall of sella turcica, which is located on the body of the sphenoid, the greater wing of the sphenoid, the cribriform plate, and the foramen cecum are commonly used after age 7 as stable reference structures for analyses of serial lateral radiographic cephalograms.

The spheno-occipital synchondrosis, between the body of the sphenoid and occipital bones, is most prominent throughout the period of active craniofacial growth and fuses shortly after puberty (Figure 8-12). Once synostosis occurs, growth of the cranial base, especially in the anteroposterior direction, is essentially over. Subsequent changes in the form of the cranial base, such as in the angulation of the basioccipital bone relative to the anterior cranial base, for example, must come about as a result of bone remodeling.

During the early postnatal years, the cranial base undergoes a dramatic shift in it growth pattern (Figure 8-13). Anterior (nasion–sella) and posterior (sella–basion) cranial base lengths, as well as cranial base angulation (nasion–sella–basion), exhibit greater growth changes during the first 2 to 3 postnatal years than any time thereafter. For example, cranial base angulation decreases more than twice as much during the first 2 postnatal years than between 2 and 17 years of age. Growth continues after 2 years of age, but the changes are smaller and more steady.

Between birth and 17 years of age, the anterior cranial base grows approximately 36% (males) to 53% (females) more than the posterior cranial base, with most of the differences due to the growth changes that occur during the first few years.[25] It is important to understand that

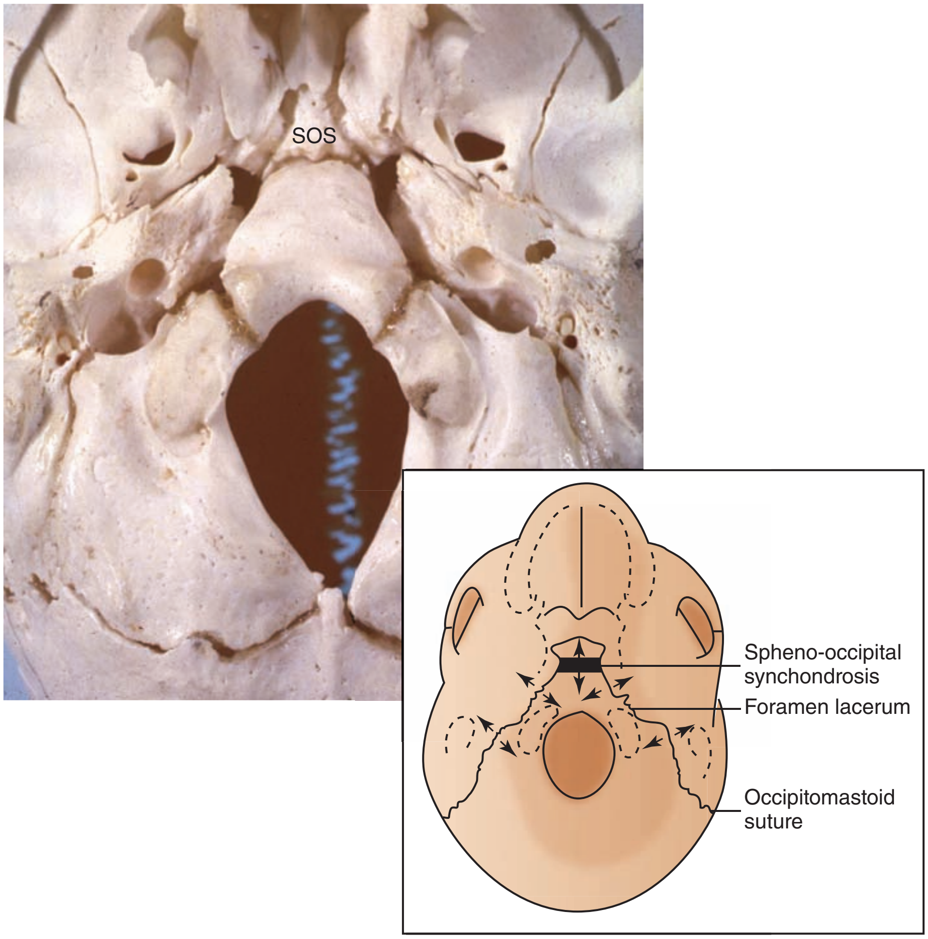


FIGURE 8-12 Basal view of a juvenile human indicating the spheno-occipital synchondrosis (*SOS*).

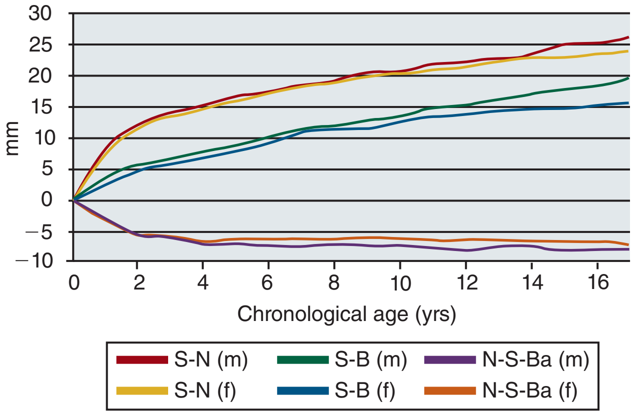


FIGURE 8-13 Male (*m*) and female (*f*) cranial base growth changes from birth through 17 years of age. *(Data from Ohtsuki et al.[25])*

the anterior cranial base grows more and is also more mature (i.e., closer to its adult size) than the posterior cranial base throughout the postnatal growth. Longitudinal analyses have shown that the anterior cranial base has already attained approximately 86% to 87% of its adult size by 4.5 years of age, while the posterior cranial base has attained only 80% to 83% of its adult size (Figure 8-14). The relative maturity differences between the anterior and posterior cranial base lengths are maintained throughout postnatal growth.

Anterior and posterior cranial base lengths increase due to bony deposition, as well as growth at the spheno-occipital and sphenoethmoidal synchondroses. Postnatally, the posterior cranial base becomes longer primarily due to growth at the spheno-occipital synchondrosis. Histologic studies have shown that the spheno-occipital synchondrosis fuses at approximately 16 to 17 years in females and 18 to 19 years in males.[27] Radiographically, the spheno-occipital synchondrosis shows active growth until approximately 10 to 13 years of age, at which time closure starts superiorly and continues inferiorly around 11 to 14 years in females and 13 to 16 years in males.[28,29]

Because both landmarks are commonly used to describe growth of the anterior cranial base, it is important to distinguish the changes that occur at nasion from those that occur at foramen cecum. After fusion of the sphenoethmoidal synchondrosis, which occurs at approximately 7 to 8 years of age,[25,27] increases in the distance between sella and foramen cecum are due primarily to the posterior and superior drift of sella turcica. The distance sella–nasion, on the other hand, continues to increase, primarily due to bony apposition on the outer surface of the frontal bone associated with the development of the frontal sinus (the earliest pneumatization of the frontal sinus occurs around 2 years of age[30]). The anterior cranial fossa continues to expand slightly, and the frontal sinus becomes more prominent. As a result, the frontal bone and root of the nose become more anteriorly located. Ford[31] estimated that the frontal bone drifts anteriorly approximately 7 mm between the time that the sphenoethmoidal synchondrosis fuses and adulthood.

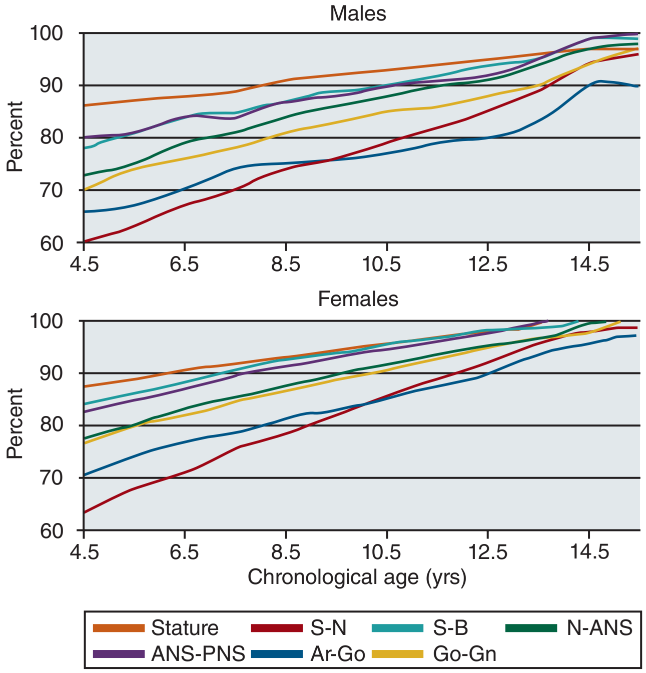


FIGURE 8-14 Craniofacial growth maturity gradient of males and females. *(Adapted from Buschang et al.[26]).*

MIDFACE/NASOMAXILLARY COMPLEX

The midface, or nasomaxillary complex, is composed of the paired maxillae, nasal bones, zygomatic bones, lacrimal bones, palatine bones, and, within the nasal cavity, the turbinates and vomer. Prenatally, human fetuses also have left and right premaxillary bones; however, these normally fuse with the maxillae within 3 to 5 years after birth (Figure 8-15).

The midface is connected to the neurocranium by a circummaxillary suture system and, toward the midline, by the cartilaginous nasal capsule, nasal septum, and vomer (Figure 8-16). There is also an intermaxillary suture system composed of the midpalatal, transpalatal, intermaxillary, and internasal sutures. With the exception of the inferior turbinates, all the bones composing the midface are formed intramembranously from a connective tissue mass.

Development of the Midface

Embryonically, the bones comprising the nasomaxillary complex arise from neural crest cells within the maxillary process of the first branchial arch. Like the bones of the cranial vault, the bones comprising the nasomaxillary complex have no cartilaginous precursors and rely on intramembranous ossification for their development. The process by which initial bone formation occurs differs from that of the cranial vault bones. Whereas the bones of the cranial vault arise within a desmocranial membrane, centers of ossification for the nasomaxillary bones develop as blastemas directly within the mesenchyme. These blastemas of bone are then surrounded by

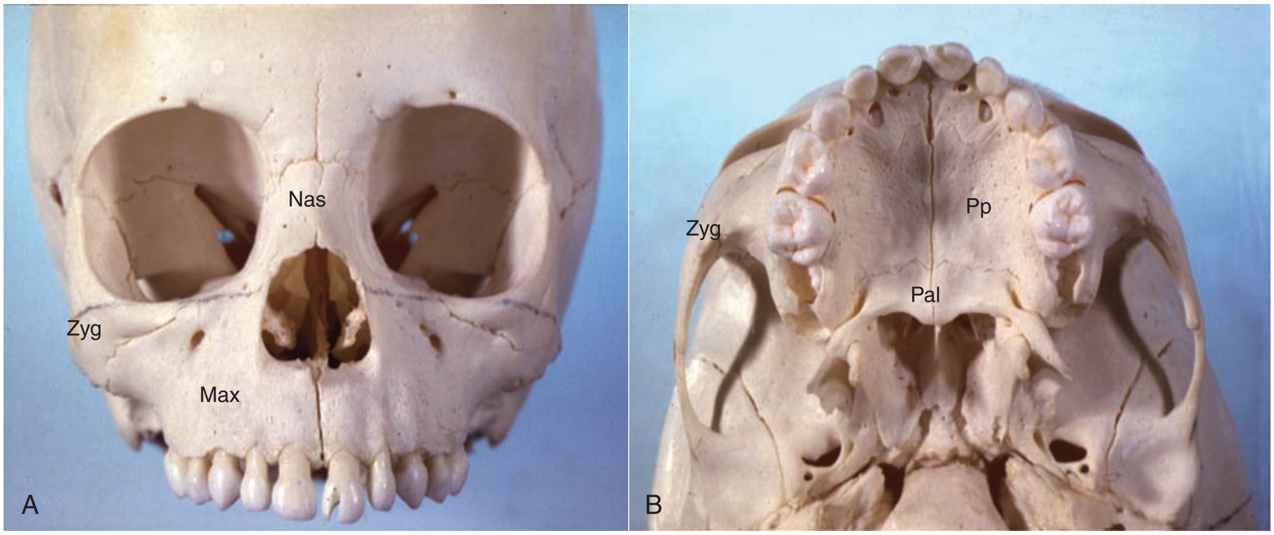


FIGURE 8-15 Frontal and basal views of a juvenile human indicating the bones comprising the midface. *Max*, Maxilla; *Nas*, nasal bones; *Zyg*, zygomatic bones; *Pal*, palatine bones; *Pp*, palatal processes of the maxillary bones.

a periosteum that provides the source of new osteoblastic cells and thus for enlargement of the skeletal element. Studies have shown that signaling mechanisms associated with the development, growth, and maintenance of the facial sutures are dependent on the presence of the nasal capsular cartilage, which appears to play a role similar to the dura mater in sutures of the cranial vault.[6,32]

Virtually all of the major centers of ossification within the midface can be seen at approximately 7 to 8 weeks gestation. At 6 weeks gestation, the palatal shelves, which are soft tissue extensions of the embryonic maxillary processes of the first branchial arches, elevate within the oral cavity, where they will give rise to the hard and soft palate. The palatal shelves begin to ossify at 7 to 8 weeks gestation, with the two bone fronts of the palatal processes each extending medially to form the secondary palate, composed of processes from the maxillary bones and from the palatine bones, as they meet in the midline where they form the midpalatal suture.

Development of the nasomaxillary complex proceeds laterally and anteroposteriorly with expansion of the brain and cranial cavity and expansion of the oral cavity and oronasal pharynx. Also throughout the fetal period, anterior and inferior growth of the nasal septal cartilage, which is an extension of the anterior cranial base, is most prominent. The cartilaginous nasal capsule, which envelops the nasal cavity laterally, is primarily structural and contributes little to the overall growth of the nasomaxillary complex other than possible expression of growth factors that support the facial sutures (Figure 8-17). Thus, the primary factors influencing the growth of the nasomaxillary complex from the late embryonic period and throughout the fetal period and the juvenile period postnatally are expansion of the brain and cranial vault and growth of the anterior cranial base, including in particular anterior and inferior growth of the nasal septum, as well as expansion of the nasal cavity and oronasal pharynx.

Postnatal Growth of the Midface

At the time of birth, the midface is well developed but diminutive relative to the neurocranium. The circummaxillary and intermaxillary sutures are all present and active as sites of bone growth. The nasal capsule and midline nasal septum are still primarily cartilaginous and continuous with the rest of the chondrocranium from the anterior cranial base. The septum is also very actively growing by means of interstitial cartilaginous growth, leading to significant anterior and vertical growth of the midface through the first several years of life.

With the exception of the nasal septum, postnatal development of the nasomaxillary complex occurs via intramembranous ossification. Growth at the circummaxillary and intermaxillary sutures occurs in response to midfacial displacements. Inferior, anterior, and lateral displacements of the midface, as well as concomitant sutural growth, account for the majority of vertical, anteroposterior, and transverse changes that occur, during both childhood and adolescence (Figure 8-18). Along with displacements, extensive surface remodeling takes place over the entire nasomaxillary complex, especially along its posterior and superior aspects.

As long as the midface undergoes displacement, sutural growth occurs, with the amounts of bony apposition being related directly to amounts of sutural separation. Growth continues until the sutures fuse. The premaxillary/maxillary suture closes at approximately 3 to 5 years of age.[34] The midpalatal and transpalatal maxillary sutures, which are the major intermaxillary growth sites associated with transverse and anteroposterior maxillary growth, have been reported to close

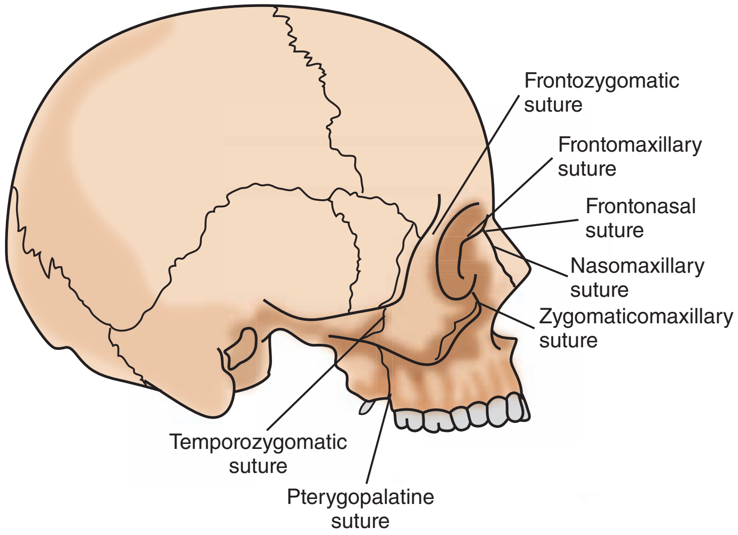


FIGURE 8-16 Location of the circummaxillary suture system articulating the midface with the neurocranium.

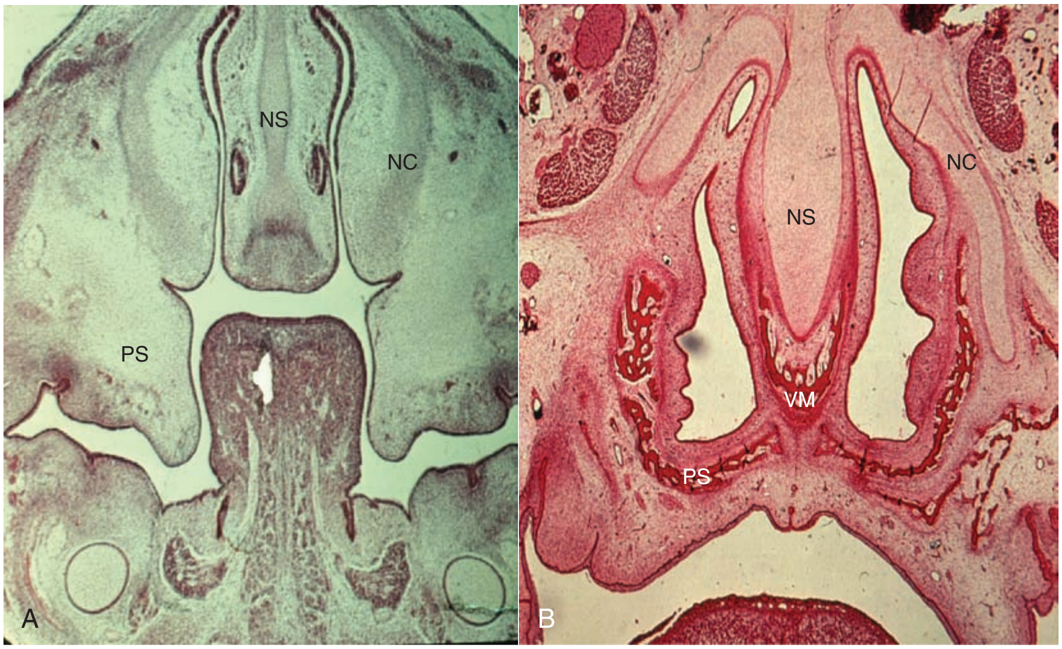


FIGURE 8-17 Frontal histologic sections of human fetuses at approximate ages of 5 weeks gestation **(A)** and 11 weeks gestation **(B)** (hematoxylin and eosin–stained). *NS*, Nasal septal cartilage; *NC*, nasal capsular cartilage; *V*, vomer; *PS*, palatal shelves.

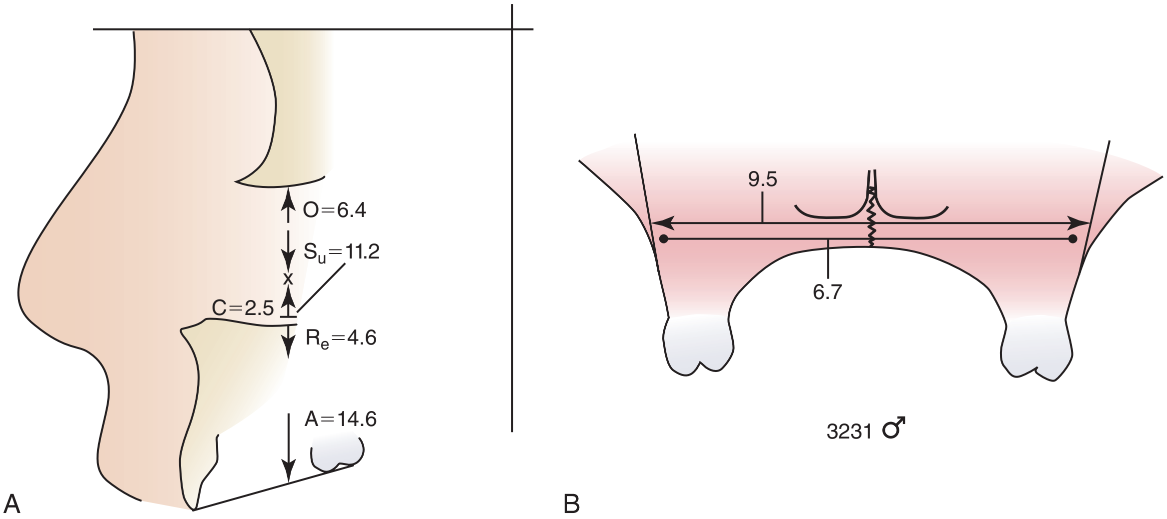


FIGURE 8-18 **(A)** Sutural displacement (S_u), apposition of the orbital floor (O), resorption of the nasal floor (R_e), apposition at the infrazygomatic creast (C), and dentoalveolar development (A) from 4 years of age through adulthood in 9 boys. **(B)** Width changes (mm) of the maxilla and lateral implants between 3.9 and 17.7 years of age. *(From Björk and Skieller.[33])*

between 15 and 18 years of age[35] and 20 to 25 years of age,[36] depending on the criteria on which closure is based. Although data are limited, it appears that closure of the circummaxillary sutures occurs somewhat later than closure of the intermaxillary sutures.

The midface undergoes a complex remodeling pattern throughout childhood and adolescence (Figure 8-19). As the midface is displaced anteriorly, compensatory bony deposition occurs along the posterior margin of the maxillary tuberosity, resulting in an increase in the length of the entire maxilla and of the dental arches.[37] The posterior maxilla is a major remodeling site that accounts for most increases in maxillary length as the cortices of the maxillary tuberosity drift posteriorly. The anterior periosteal surface of the maxilla is slightly resorptive, while the buccal surfaces undergo substantial bony deposition.

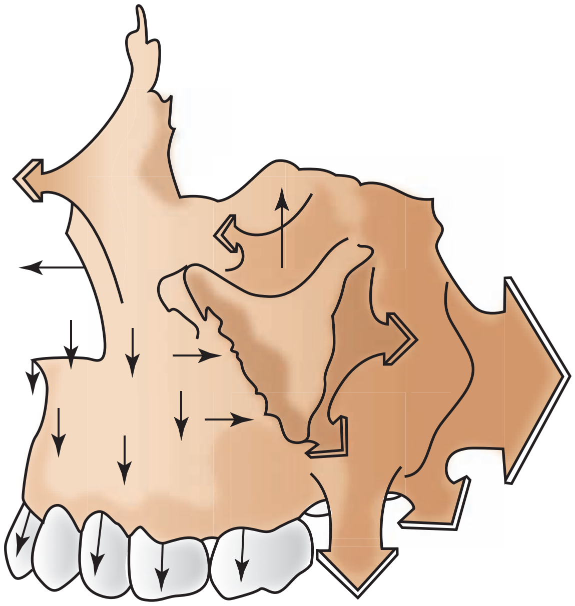


FIGURE 8-19 Maxillary remodeling, with the sizes of the arrows indicating relative amounts of change and with *dark* and *light arrows* indicating resorption and apposition, respectively. *(From Enlow.[37])*

From the sagittal perspective, the area of the anterior nasal spine drifts inferiorly and slightly posteriorly; A-point also drifts inferiorly and slightly more posteriorly than anterior nasal spine. For every 4 mm that the posterior nasal spine drifts posteriorly, it drifts approximately 3 mm inferiorly. Associated with inferior displacement of the midfacial complex, bony resorption occurs along the floor of the nasal cavity, whereas apposition occurs on the roof of the oral cavity (i.e., palate) and orbital floor. Implant studies suggest that for every 11 mm of inferior midfacial displacement, the orbital floor drifts superiorly 6 mm and the nasal floor drifts inferiorly 5 mm.[33,38] Thus, midfacial height increases are due to the combined effects of inferior drift and displacements (see Figure 8-18). The height of the midface is further increased by continued development of the dentition and alveolar bone. The lack of naturally stable structures on the surface of the midfacial complex makes superimposition difficult.

The width of the midface at the time of birth is proportionately large due to the precocious development of the eyes, which are the central features of the neonatal midface. Growth in width during the first 2 to 3 years after birth is associated with expansion of the brain laterally and anteroposteriorly, which brings the eyes laterally with it. As this occurs, the sutures separating the two halves of the frontal bone (metopic suture), the two nasal bones (internasal suture), the two maxillae (intermaxillary suture), and the two palatine bones (midpalatal suture) are in excellent positions to respond by secondary, compensatory bone formation. It has been estimated that the midalveolar and bijugale widths of the maxilla increase approximately 5 and 6 mm, respectively, between 7.6 and 16.5 years of age; rates of growth in width diminish slightly with increasing age.[39]

At the same time the midface is increasing in width, it is increasing even more dramatically in depth (anteriorly) and height (vertically). The midface increases most in height, next in depth, and least in width. As the brain and eyes grow anteriorly relative to the middle cranial base, the orbits increase in depth and the anterior cranial base lengthens, primarily as a result of growth at the sphenoethmoidal synchondrosis. Concomitantly, the nasal septum grows vertically as the midface is displaced inferiorly relative to the anterior cranial base. The combination of these two growth processes—growth in a vertical direction associated with interstitial cartilaginous growth within the nasal septum and growth in an anterior direction associated with interstitial cartilage growth within both the nasal septum and synchondroses of the cranial base—results in the typical downward and forward growth of the entire midface relative to the anterior cranial base. Surface deposition cannot account for the downward and forward midfacial growth that occurs during childhood and adolescence.

The age of approximately 7 years is something of a benchmark for growth of the midface. Growth of the central nervous system—the brain and eyes—is essentially complete at about 7 years of age. Concomitantly, the cartilage of the sphenoethmoidal synchondrosis ossifies and a suture is formed between the sphenoid and ethmoid bones at about that time. As a result, a relatively stable anterior cranial base is established extending from sella turcica to the foramen cecum. Also at about 7 years of age, the growth of the cartilages of the nasal capsule and nasal septum changes significantly. The cartilaginous nasal capsule becomes ossified and the nasal septum, which remains cartilaginous throughout life in humans, decreases significantly in growth activity. Despite these important developmental changes in the growth processes of the midface, downward and forward skeletal growth continues to be significant over the next decade or so, particularly in males during adolescence.

Growth of the nasomaxillary complex continues throughout childhood and adolescence, with substantially greater vertical than anteroposterior growth potential (Figure 8-20). By 4.5 years of age, palatal length (anterior nasal spine–posterior nasal spine) and anterior facial height (nasion–anterior nasal spine) have attained approximately 80% and 73% of their adult size, respectively (see Figure 8-14). In terms of absolute growth, midfacial heights should be expected to increase 10 to 12 mm in females and 12 to 14 mm in males between 4 and 17 years of age. Palatal length should be expected to increase 8 to 10 mm over the same time period. Because nasion drifts anteriorly at approximately the same rate as the midface is displaced anteriorly, the sella–nasion–anterior nasal spine (SNA) angle shows little or

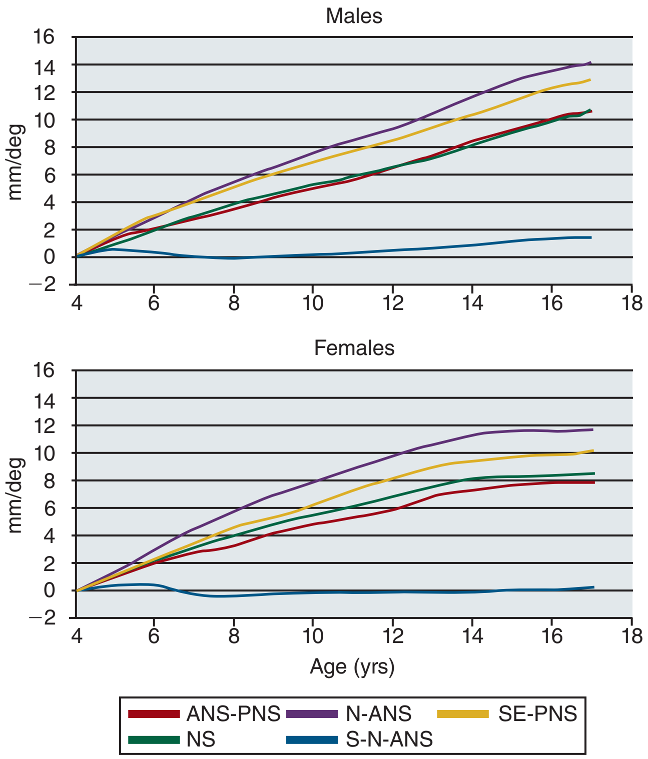
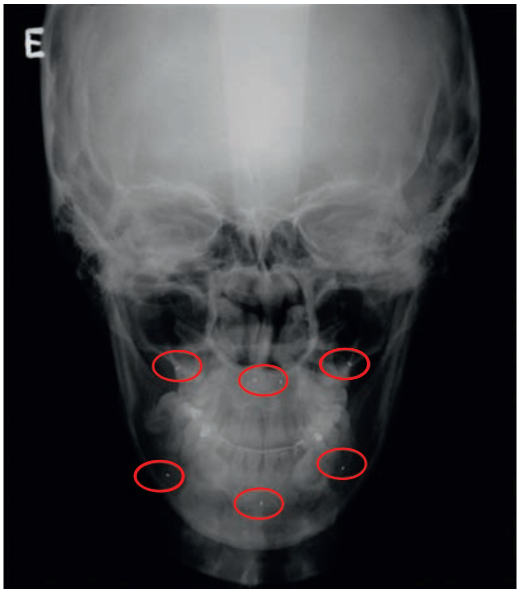


FIGURE 8-20 Maxillary growth changes between 4 and 17 years of age of males and females. *(Adapted from data provided by Bhatia and Leighton.[40])*



References	Ages (Yrs)	Mx	Md
Björk and Skieller, 1977	4-21	.42	N/A
Korn and Baumrind, 1990	8.5-15.5	.43	.28
Gandini & Buschang, 2000	13.9-16.7	.27	0.19
Iseri and Solow, 2000	7-12	N/A	.22
	13-18	N/A	.13

FIGURE 8-21 Transverse expansion (mm/yr) of metallic bone markers inserted into the maxillary (*Mx*) and mandibular (*Md*) basal structures.

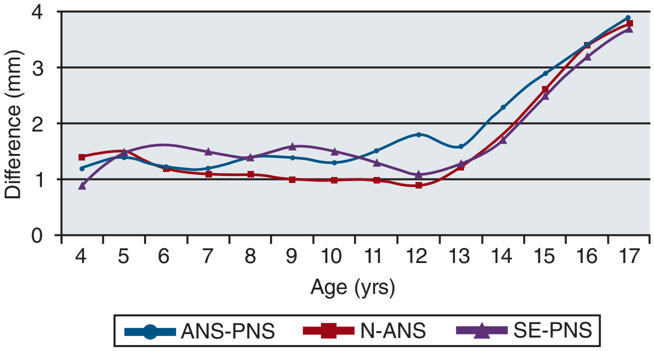


FIGURE 8-22 Sex differences (male minus female) in maxillary size. *(Adapted from data from Bhatia and Leighton.[40])*

no change during childhood or adolescence. Although vertical maxillary growth rates peak during adolescence, at approximately the same time as stature, anteroposterior maxillary growth remains more or less constant, with no distinct adolescent spurt.

Due to differences in the relative displacements of the bones, the midface undergoes varying amounts of vertical and transverse true rotation. True rotation is independent of remodeling and refers to changes that occur over time in the positions of basal bone; it is commonly assessed with metallic implants placed into the mandibles and maxillae of growing children.[41] From the sagittal perspective, most children undergo true forward or counterclockwise (subject facing to the right) rotation of the midface, due to greater inferior displacement of the posterior than anterior maxilla. The true rotation that occurs tends to be covered up or hidden by the resorption that occurs on the nasal floor. For example, true forward rotation is associated with greater resorption in the anterior than posterior aspect of the nasal floor. Due to greater transverse displacements posteriorly than anteriorly, the midfacial complex also exhibits transverse rotation around the midpalatal suture (Figure 8-21). As a result, there is greater sutural growth in the posterior than anterior aspect of the midpalatal suture. Cephalometric analyses using metallic implants have shown that the posterior maxilla expands approximately 0.27 to 0.43 mm/yr, with greater expansion occurring during childhood than during adolescence.[33,38]

There are definite sex differences in maxillary growth throughout childhood and adolescence (Figure 8-22), with males being larger and growing more than females. Size differences, averaging between 1 and 1.5 mm, are small but consistent during childhood. Sexual dimorphism increases substantially throughout the midfacial

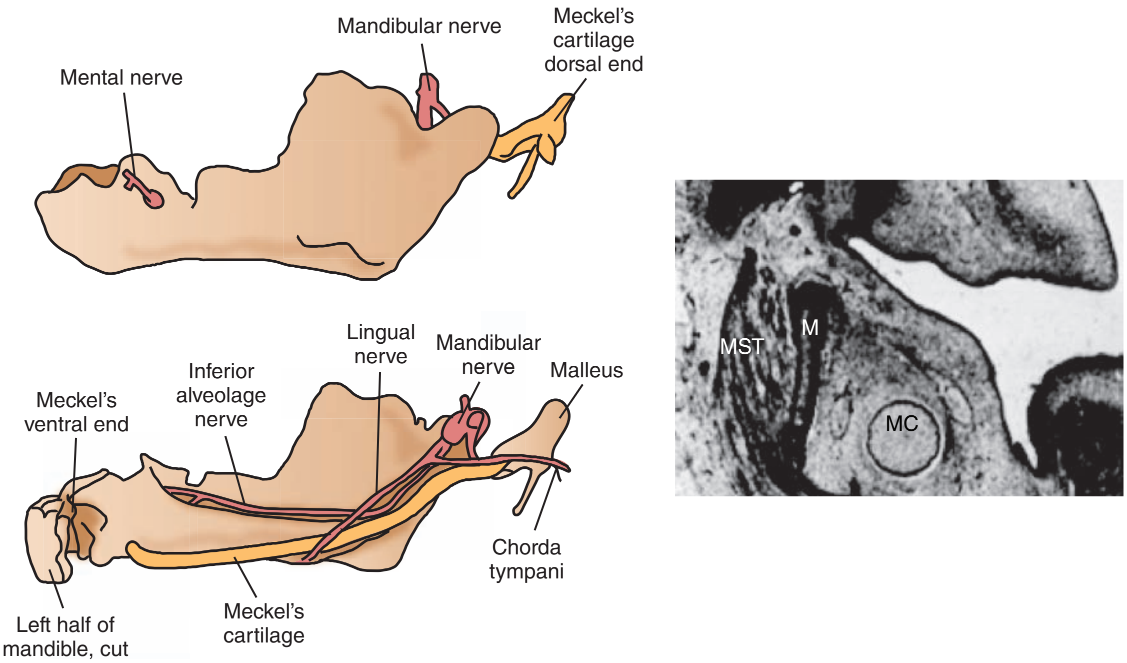


FIGURE 8-23 Drawings of a fetal mandible with lateral *(top left)* and medial *(bottom left)* views. *Right,* Photomicrograph of coronal view of human fetus indicating Meckel's cartilage medial to the mandible (*M*). *MST*, Masseter muscle. *(Drawings adapted from Warwick and Williams.[46])*

complex during adolescence, with differences of approximately 4 mm in maxillary length (anterior nasal spine to posterior nasal spine [ANS-PNS]) and upper facial height (nasion to anterior nasal spine [N-ANS]) at 17 years of age.[40] Males also have a significantly wider midfaces than females, with differences approximating 5 to 7 mm during late adolescence.[45] The primary reason that adult males are larger than adult females is the 2 extra years of childhood growth that males have; males enter the adolescence phase of growth at approximately 12 years of age, while females enter at 10 years. Males are also larger than females because they experience a more intense adolescent spurt, but this contributes less to the sex differences observed.

MANDIBLE

Development of the Mandible

The mandible develops bilaterally within the mandibular processes of the first branchial arch. Each embryonic mandibular process contains a rodlike cartilaginous core, Meckel's cartilage, which is an extension of the chondrocranium into the splanchnocranium, and accompanying inferior alveolar artery, vein, and nerve. Proximally, Meckel's cartilage articulates with the cartilaginous cranial base in the petrous region of the temporal bone, where it gives rise to the malleus and incus bones of the inner ear.

By 6 weeks gestation, a center of ossification appears in the perichondrial membrane lateral to Meckel's cartilage. It is critical to note that ossification of the mandible takes place in membrane *lateral and adjacent* to Meckel's cartilage, and *not within* Meckel's cartilage itself (Figure 8-23). Therefore, it is clear that the mandible develops and subsequently grows by means of intramembranous ossification, and not through endochondral ossification and replacement of Meckel's cartilage.

Intramembranous ossification of the body of the mandible proceeds distally toward the mental symphysis and proximally up to the region of the mandibular foramen. As it does so, Meckel's cartilage begins to degenerate and involute as the inferoalveolar neurovascular bundle becomes enveloped by the developing mandibular bone. Meckel's cartilage completely disappears by approximately 24 weeks gestation, remaining in remnant form as the dense sphenomandibular ligament and giving rise to the malleus and incus ear ossicles.

By approximately 10 weeks gestation, the condylar process appears as a separate carrot-shaped blastema of cartilage extending from the ramus proximal to the mandibular foramen and extending up to articulate with the squamous (membranous) portion of the developing temporal bone. The articulation between the condylar cartilage and the squamous portion of the temporal bone becomes apparent as the temporomandibular joint (TMJ) by about 12 weeks gestation (Figure 8-24).

As the cartilage comprising the mandibular condyle arises "secondarily" within a skeletogenic membrane and apart from the primary embryonic cartilaginous anlagen, it is referred to as a *secondary cartilage* (Figure

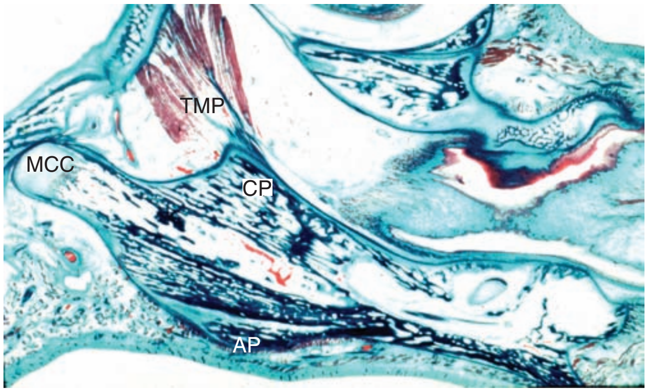


FIGURE 8-24 Parasagittal histologic section of human fetus (approximately 12 weeks gestation) (hematoxylin and eosin–stained). *MCC*, Mandibular condylar cartilage; *CP*, coronoid process; *AP*, angular process; *TMP*, temporalis muscle.

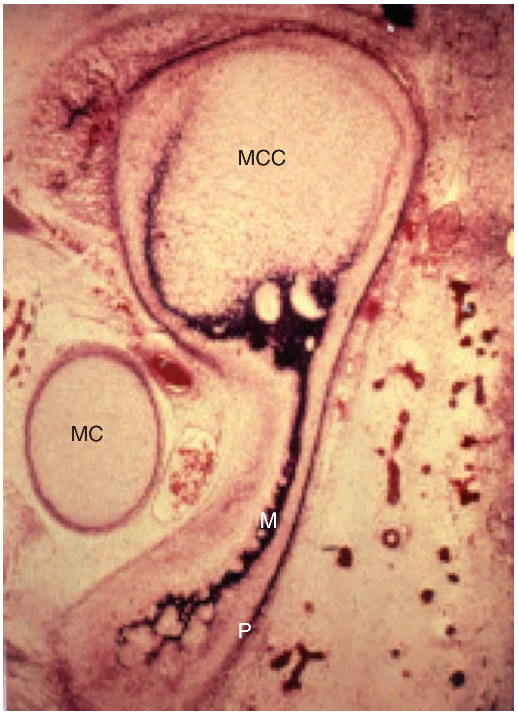


FIGURE 8-25 Frontal histologic section of a human fetus (approximately 8 weeks gestation) (hematoxylin and eosin–stained). The bone comprising the body and ramus of the mandible (*M*) originates in membrane lateral to Meckel's cartilage (*MC*). The periosteal membrane enveloping the mandible gives rise *secondarily* to the mandibular condylar cartilage (*MCC*).

8-25). Secondary cartilage is a unique type of skeletal tissue that has the characteristics of both intramembranous bone and certain histologic and functional features of hyaline growth cartilage. Secondary cartilage is formed in areas of precocious stresses and strains within intramembranous bones, as well as in areas of rapid development and growth of bone.[47–51] Within the craniofacial complex, the angular and the coronoid processes of the mandible also may exhibit the presence of secondary cartilage because these are sites of very rapid bone growth associated with the function of the muscles of mastication. In addition, secondary cartilage may be found in areas of sutures that are characterized by rapid intramembranous bone growth and biomechanical load associated with separation and bending at the articular surfaces.

At birth, the two halves of the mandible are separated in the midline by a fibrous articulation, the mental symphysis, which will fuse by the end of the first year of life. Each half of the mandible is characterized anatomically by (1) a *condyle*, which articulates with the temporal bone to make up the TMJ; (2) a *ramus*, which extends roughly vertically-inferiorly from the TMJ and provides insertions for the muscles of mastication; and (3) a *corpus*, or body, which extends roughly horizontally-anteriorly to provide a base for the mandibular dental arch and house the inferior alveolar neurovascular bundle. Each of these anatomic structures can also be considered in terms of overlapping functional units (Figure 8-26). The mandibular condyle is closely related to the articular function of the TMJ and movements of the mandible. At the same time, the condylar cartilage also plays a significant role in mandibular growth.[52,53] Variation in the function of the TMJ, such as might occur in association with differences in mastication, jaw movements, and jaw position, for example, is highly likely to affect its growth and form. The gonial region of the mandible, at the inferior aspect of the ramus, is related to the function of the masseter and medial pterygoid complex of muscles, while the coronoid process is primarily related to the temporalis muscle. Variation in the growth and form of each of these regions is due in large part to variation in the function of the muscles of mastication. The alveolar process of the mandible functions to provide support for the dentition. Finally, the body of the mandible, extending from the mandibular foramen to the mental process, provides support and structural connection between the various functional components of the mandible.

Histomorphology of the Mandibular Condyle

Because of its significant role in the growth, function, and adaptation of the mandible, it is important to consider the histomorphology of the growing TMJ in detail. In doing so, it is interesting to note the striking similarity between the histomorphology of the mandibular condyle and a growing suture. Just as a suture can be considered as a specialization of an osteogenic membrane (i.e., periosteum and dura mater), the condylar cartilage can also be considered as a specialization of periosteum. As with sutures, growth of the mandibular condyle tends to be relatively highly responsive to mechanical, functional, and hormonal stimuli both at the time of development and throughout the growth period, similar to intramembranous bone development elsewhere.

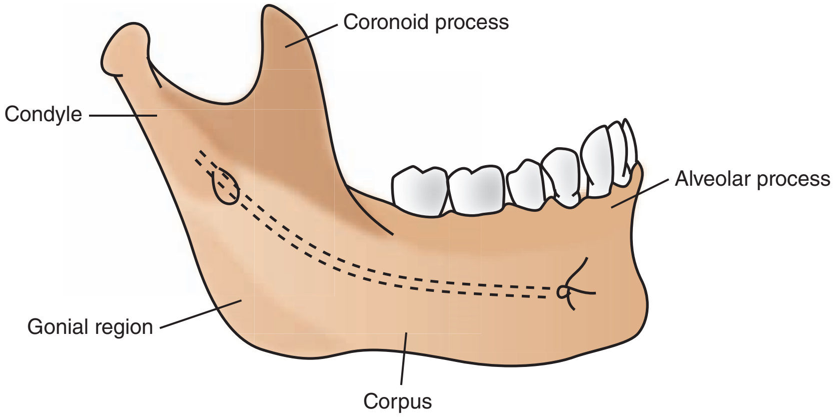


FIGURE 8-26 Major functional units of the mandible.

The secondary cartilage composing both the condylar and the temporal portion of the TMJ can be divided into two general layers: an articular tissue layer and a subarticular growth layer. Each of these layers is present in the neonate and remains in the condyle through maturity. However, the absolute and relative size of the layers and their growth-related activity may vary considerably, depending on the overall rate and amount of condylar growth and on the functional requirements placed on the condyle and TMJ.[54–60]

The articular layer of the joint surface of the mandibular condyle and temporal portion of the TMJ is continuous with the outer, fibrous layer of the bilaminar periosteum encapsulating the condylar neck and temporal bone, respectively. This tissue consists of a largely avascular dense fibroelastic connective tissue whose collagen fibers are oriented parallel to the articular surface. The articular layer varies in thickness along the condylar head and temporal joint surface, increasing in thickness in the superior aspect of the condyle and on the articular eminence of the temporal bone, where compressive forces associated with mastication are most readily apparent.[59] The fibrous articular layer of the mandibular condyle and that found in the temporal fossa and articular eminence are identical functionally to the articular cartilage found in diarthroideal joints of postcranial long bones, but their origin and histologic composition are completely different. Articular cartilage is derived from the primary cartilaginous anlagen at the ends of long bones; the articular tissue of the TMJ is a specialization of the fibrous layer of periosteum that covers the mandible and temporal bone.

Like other growth cartilages, the histomorphology of the subarticular condylar cartilage is organized into a series of layers that are related to the development and maturation of the skeletal tissues (Table 8-1, Figure 8-27). In general, at least three layers can be readily identified. The *proliferative*, or *prechondroblastic, layer* immediately deep to the articular layer is continuous with the osteogenic layer of the periosteal membrane along the condylar neck.[56,60,64,65] Its outer portion is composed of undifferentiated mesenchymal cells that differentiate into skeletoblastic stem cells or prechondroblasts. Morphologically, this layer appears densely packed with spindle-shaped cells that increase in size and become increasingly separated due to production of intercellular

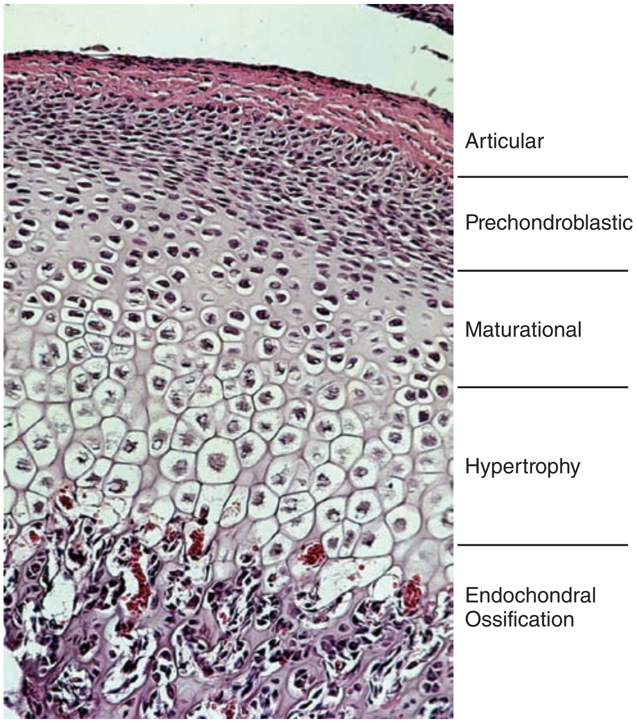


FIGURE 8-27 Histologic section indicating the various layers of the secondary cartilage in a growing mandibular condyle (hematoxylin and eosin–stained).

TABLE 8-1 Comparison of Terminology Used to Describe the Histomorphology of the Condylar Cartilage

Blackwood[61]	Durkin et al.[62]	Wright & Moffett[60]	Petrovic et al.[64]	Thilander et al.[55]	Carlson et al.[76]	Luder[53]
Articular zone	Resting surface articular layer	Articular layer	Fibrous capsule	Surface articular layer	Fibrous articular tissue	*Perichondrium* Articular layer
	Transitional or proliferative layer	Proliferative layer	Prechondroblastic layer	Proliferative layer	Prechondroblastic (proliferative) layer	Polymorphic cell layer
						Flattened cell layer (1 and 2)
			Zone of Maturation			*Hyaline Cartilage*
Intermediate zone		Zone of matrix production	Functional chondroblasts		Chondroblastic zone (maturation and hypertrophy)	Flattened cell layer (3)
				Hypertrophic zone (nonmineralized)		
						Upper hypertrophic cell layer
Hypertrophic cartilage	Hypertrophic cartilage	Zone of cell hypertrophy	Hypertrophic chondroblasts			
	Erosion zone			Hypertrophic zone (mineralized)		
			Zone of Erosion			Lower hypertrophic cell layer
			Degenerating chondroblasts			
		Zone of calcification and resorption				
	Subchondral bone		Zone of endochondral ossification		Zone of bone deposition	

matrix within the inner region of the proliferative zone. Once formed, the cartilage cells undergo very few mitoses.

The *chondroblastic layer* of the condylar cartilage is composed of two subzones—the zone of maturation and the zone of hypertrophy. The chondroblastic layer contains larger, spherical, maturing chondrocytes arranged in an apparently random fashion. There is significantly less extracellular matrix than is found in the growth plates of developing long bones, which are comprised of primary cartilage. These cells hypertrophy, the nuclei become pyknotic, and the cytoplasm is increasingly evacuated as the cells are encroached upon by the endosteal region of the condyle. The intercellular matrix begins to mineralize within the distal most three to five layers of hypertrophying cells, and it is subsequently eroded away by chondroblastic-osteoclastic activity at the *zone of endochondral ossification*.

Detailed histologic analysis of human autopsy specimens of the human TMJ has demonstrated progressive changes in the thickness and presumed growth activity of the condyle cartilage throughout development.[66–70] These changes appear to be coordinated with functional changes associated with occlusal development.[53,56] In general, the combined growth-related layers of the condylar cartilage begin as a relatively thick structure in the neonate (1.25 to 1.5 mm thick) but become much thinner (0.3 mm) by the mixed dentition stage. The cartilage remains generally thin but well defined and actively growing in the permanent dentition stage until, by age 20 to 30 years, the cartilage essentially disappears and the condyle is capped by a bony plate. Even in adults, however, it is not unusual to see areas of hyaline cartilage ("cartilage islands") deep to the articular layer in the condyle.

The subarticular region of the temporal component of the TMJ has the same tissue layers as the condyle; however, they are substantially less prominent.[59] Morphologically, the temporal component of the TMJ in the neonate is essentially flat and the articular disc interposed between the condyle and temporal bone is highly vascular. During the period of the primary dentition, at approximately 3 years of age, the temporal surface takes on its characteristic S-shaped contour and the articular disc becomes avascular in its central region. Thereafter, the temporal surface of the TMJ grows more slowly, with the mandibular fossa becoming deeper as the articular eminence becomes steeper primarily through the process of bone deposition on the articular eminence and, to a lesser extent, by resorption of bone in the posterosuperior region of the fossa, as well as endosteal deposition in the superior aspect of the fossa. This increase in the contour of the temporal component of the TMJ normally continues until the fourth decade of life.

In summary, the mandibular condylar cartilage is a secondary cartilage that in subadult individuals serves both as a site of growth and as a place of articulation. As such, it displays functional characteristics of both a growth plate and an articular cartilage, but it differs from both in fundamental aspects of its development and structure throughout ontogeny. Its most superficial layers are not cartilaginous in phenotype but rather are perichondrial in origin. Importantly, the chondrocytes of the mandibular condylar cartilage are derived via mitosis in cells that are themselves not chondrocytes, similar to embryonic cartilage[62] but not to the growth plate in which the cells that proliferate are chondrocytes. Finally, the prechondrogenic phenotype of these dividing cells in the mandibular condylar cartilage can be readily modulated to a preosteogenic phenotype by changes in the periarticular environment. Taken together, these features define a tissue with structural and growth characteristics that are consistent with the concept of an adaptive *growth site* and set it apart from cartilaginous growth centers.

Mechanisms of Condylar Growth

The mandibular condylar cartilage was initially considered to be a growth center with an intrinsic capacity for tissue-separating growth.[2,71] However, it is now generally understood that growth of the mandibular condylar cartilage is highly adaptive and responsive to growth in adjacent regions, particularly the maxilla.[72] Numerous experimental studies were conducted over the past several decades to assess the role that function and jaw position, in particular, might play in influencing the postnatal growth of the mandibular condyle. For example, in a number of studies involving anterior postural change of the mandible in rats, Petrovic and associates[64,65,73,74] consistently found a significant increase in the overall length of the mandible. Similarly, in growing monkeys, McNamara and Carlson[75] found that the condylar cartilage became thickened and hyperplastic within 2 weeks of placement of an appliance that prompted protrusion on closing (Figure 8-28). From these experiments, Petrovic and colleagues developed a "cybernetic" model of mandibular growth regulation referred to as the "servosystem hypothesis of mandibular growth"[76] (Figure 8-29).

There has been a significant expansion of knowledge concerning the molecular biology and cellular dynamics associated with growth of the condylar cartilage. It has been shown, for example, that fibroblast growth factor (FGF) and insulin-like growth factor (IGF) are present in the matrix and cell surfaces of the condylar cartilage and that they vary according to their specific location, much like in sutures. Less is known of the presence or importance of transforming growth factor-beta (Tgf-β) or other growth factors, and knowledge of hormonal influences on growth of the condylar cartilage is even more rudimentary and somewhat contradictory.[77–79]

Several studies have begun to explore the effect of mandibular function and position on mandibular growth

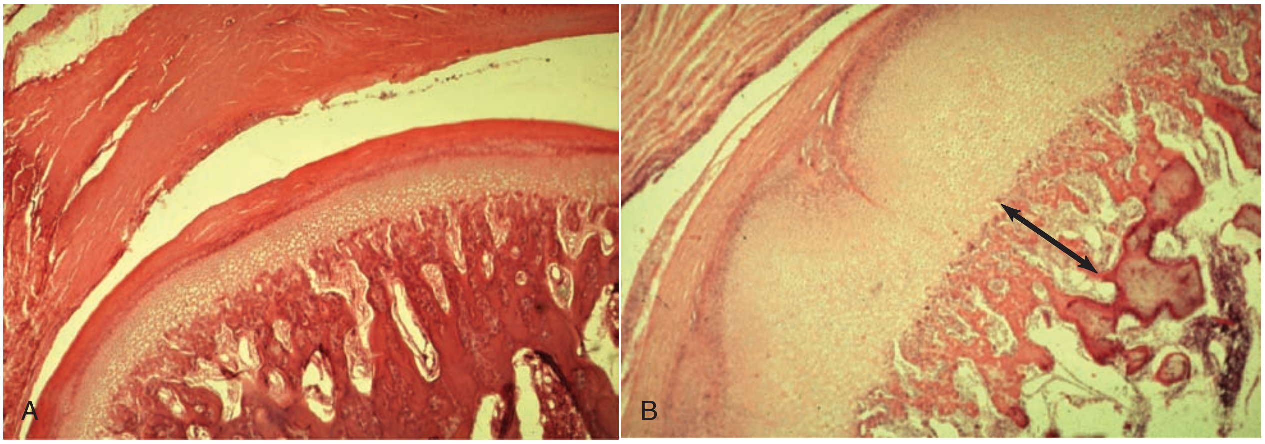


FIGURE 8-28 Parasagittal sections of the mandibular condyle from control **(A)** and experimental **(B)** rhesus monkeys (hematoxylin and eosin–stained). The experimental animal was treated with an intraoral protrusive appliance for a period of 6 weeks. Note the hypertrophy of the condylar cartilage and the significant increase in new bone formation (*arrow*).

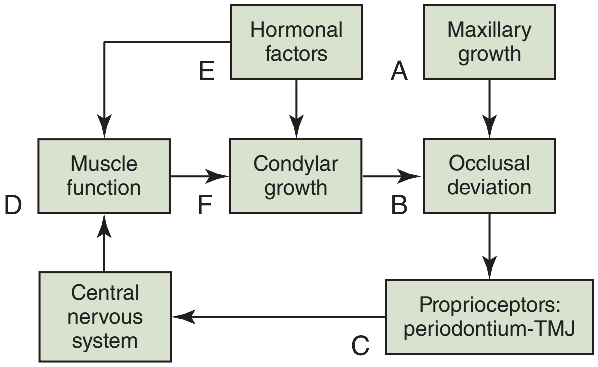


FIGURE 8-29 Simplified explanation of Petrovic's "servosystem hypothesis of mandibular growth." Independent growth of the maxilla **(A)** creates a minor occlusal deviation between the upper and lower dentition **(B).** This occlusal deviation is perceived by proprioceptors **(C),** which provide a signal to the muscles responsible for jaw protrusion to be tonically more active **(D),** which causes the mandibular condyle to become slightly more anteriorly located within the temporomandibular joint, thus stimulating condylar growth **(F).** Muscle function and the adaptive capacity of the condyle for growth are enhanced by expression of hormonal factors **(E),** and thus condylar growth may vary depending on the maturational and hormonal status of the individual. *(From Carlson.[76])*

by using appliances that replicate the effects (e.g., increased mitotic activity, cartilage thickness) reported by investigators in the 1960s and 1970s. Fuentes and coworkers[80] used an incisor-borne appliance that prompted a crossbite in growing rats and produced a differential change in proliferation and cartilage thickness between the crossbite and noncrossbite sides. In animals wearing the appliance, gene expression for *IGF-1* and *FGF-2* and their receptors in condylar cartilage was altered from that in control rats. The changes in gene expression, which typically preceded the changes in mitotic activity and cartilage thickness, were in most instances opposite in direction between the crossbite and noncrossbite sides. Using a similar design, Hajjar and associates[81] found that rats fitted with an incisor-borne appliance that prompted anterior displacement of the mandible exhibited increased expression of both IGF-I and IGF-II mRNA and protein in the MCC. Rabie and colleagues[82–84] demonstrated that the expression of *Sox9*, type II collagen, and *Indian hedgehog (ihh)* was increased in the condylar cartilage and glenoid fossa of rats wearing the appliance for 1 to 2 weeks.

In general, these findings parallel the findings discussed previously for development of the sutures of the cranial vault. These similarities between the condylar cartilage and sutures should not be surprising given the periosteal origin of both suture mesenchyme and the secondary cartilage of the mandibular condyle.

Postnatal Growth of the Mandible

At birth, the ramus of the mandible is quite short, both in absolute terms and in proportion to the mandibular corpus. During postnatal development, the ramus becomes much more prominent, particularly in height but also in width. At the same time, the corpus increases in length, providing the necessary space for development and eruption of the mandibular dentition. Associated with these early postnatal changes in the absolute and relative sizes of the mandible are decreases in the gonial angle between the ramus and corpus and increases in the angle between the two corpora.

The mandible has the greatest postnatal growth potential of any component of the craniofacial complex. Growth changes that occur are closely associated with the functional processes that comprise the mandible, including the gonial process, coronoid process, alveolar process, and the bony attachments of the suprahyoid muscles, which are all major sites of postnatal remodeling. Although condylar growth is often assumed to be the mandible's primary growth site, it is important to note that the entire superior aspect of the ramus displays approximately the same amount of growth.

Viewed in its lateral projection, the entire posteroinferior and superior border of the ramus, including the condyle, and the posterosuperior aspect of the coronoid process are depository throughout the period of active growth. The anterior and lower borders of the ramus of the mandible are resorptive. Resorption of bone continues to occur along the anterior border of the ramus, resulting in a longer corpus and increased space for the development and eruption of the mandibular dentition (Figure 8-30). With respect to the corpus, the greatest growth changes are appositional growth of the alveolar bone associated with dental development and eruption. The symphysis, especially the superior aspect, becomes wider due to superior and posterior drift of its posterior aspect (Figure 8-31). There is resorption on the anterior aspect of the symphysis above the bony chin. The cortical region at or just above the chin is the only place on the entire surface of the mandible that remains stable during postnatal growth, which is why it serves as a useful site for superimposing successive radiographs. The inferior aspect of the anterior corpus tends to be depository, but the amounts of bone added are limited and variable.

Widening of the body of the mandible occurs through deposition of bone along the buccal surface of the mandibular corpus and transverse rotation of the right and left corpii. Expansion of the mandible also results from bony deposition along its posterior surface, which, due to its posterolateral orientation, produces a longer and wider mandibular corpus. Growth in width of the superior aspect of the ramus is somewhat more complex due to the substantial increases in height that occur. Viewed in a coronal projection, the superior aspect of the ramus and coronoid process are canted somewhat mediolaterally. As the mandibular corpus and inferior aspect of the

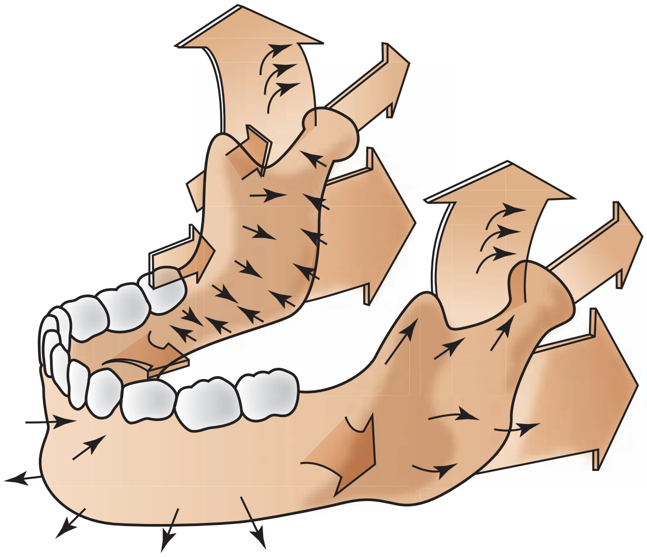


FIGURE 8-30 Mandibular remodeling, with the sizes of the arrows indicating relative amounts of change and with dark and light arrows indicating resorption and apposition, respectively. *(From Enlow and Harris.[85])*

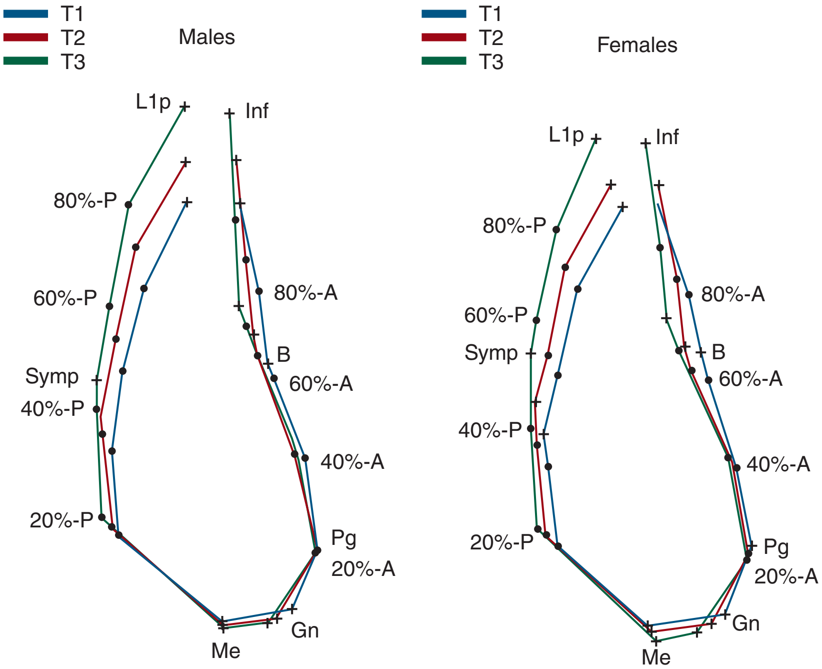


FIGURE 8-31 Remodeling changes of the symphysis between 6 (*T1*), 10 (*T2*), and 15 (*T3*) years of age. *(From Buschang et al.[86])*

ramus increase in width by deposition along the buccal surface, the buccal surface of bone on the superior aspect of the ramus is resorptive, while the lingual and superior surfaces of bone are depository.[85]

The greatest changes in mandibular growth also occur during infancy, with overall length (condylion to gnathion [Co–Gn]) increasing 15 to 18 mm during the first year, 8 to 9 mm during the second year, and then slowing down to increase approximately 5 mm during the third year. During these early years, condylar growth and remodeling of the superior aspects of the ramus are directed posteriorly and superiorly, with roughly equal amounts of growth in each direction. This orientation is important because it rapidly increases corpus length to make room for the rapidly developing dentition. After the first few postnatal years, growth of the condyle and superior ramus slows down dramatically and changes orientation toward a predominant superior direction.

By 4.5 years of age, ramus height has attained approximately 64% and 70% of its adult size for males and females, respectively (see Figure 8-14). Corpus length (Go–Gn) closely approximates the maturity pattern of midfacial height; it remains more mature than ramus height throughout postnatal growth. This supports the general principle that the vertical aspects of craniofacial growth are less mature and have greater postnatal growth potential than the anteroposterior aspects. Total mandibular length (condylion to menton [Co–Me]) undergoes the greatest increases in length (approximately 25 mm and 30 mm for female and male, respectively) between 4 and 17 years of age, followed by corpus length (gonion to pogonion [Go–Pg]; approximately 18 mm and 22 mm for females and males, respectively) and ramus height (condylion to gonion [Co–Go]; approximately 14 mm and 17 mm for females and males, respectively) (Figure 8-32). During later childhood and adolescence, the condyle shows substantially greater amounts of superior than posterior growth. For every 1 mm of posterior growth, there is 8 to 9 mm of superior growth.[79] It has been estimated that the condyles of females and males grow 2 to 2.5 and 2.5 to 3.0 mm/yr, respectively, during childhood and adolescence, with the greatest rates occurring during the earlier childhood years and during the adolescent spurt (Figure 8-33). The coronoid process and sigmoid notch follow similar growth patterns. Due to the resorption of bone that normally occurs in the gonial region, ramus height (measured from gonion to condylion) substantially underestimates the actual amount of growth that occurs at the condyle. There is approximately 1 mm of

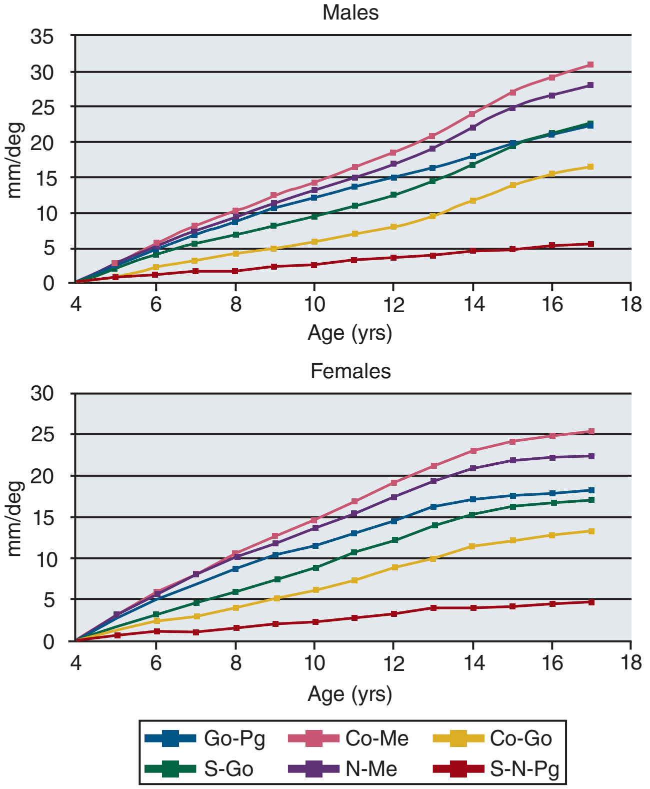


FIGURE 8-32 Mandibular growth changes between 4 and 17 years of age of males and females. *(Adapted from data provided by Bhatia and Leighton.[40])*

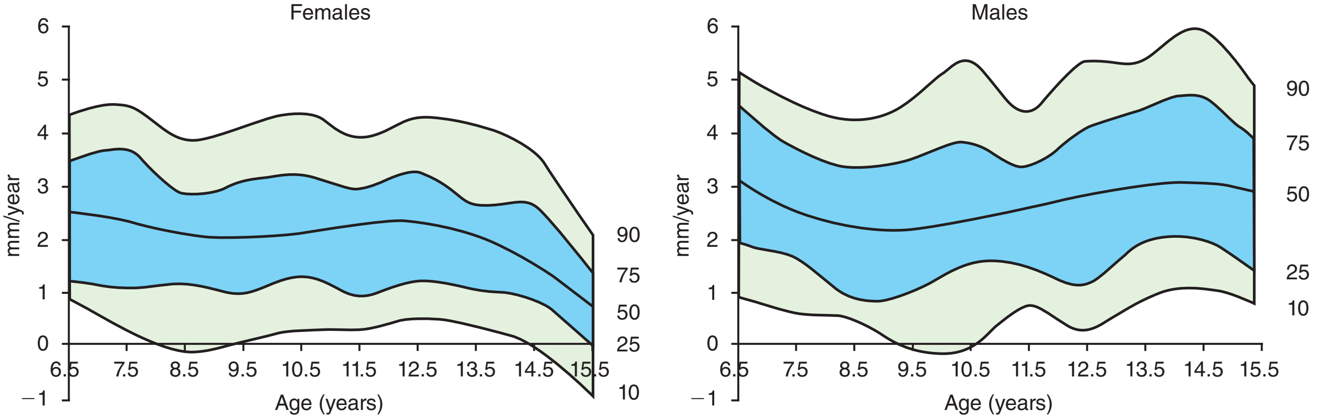
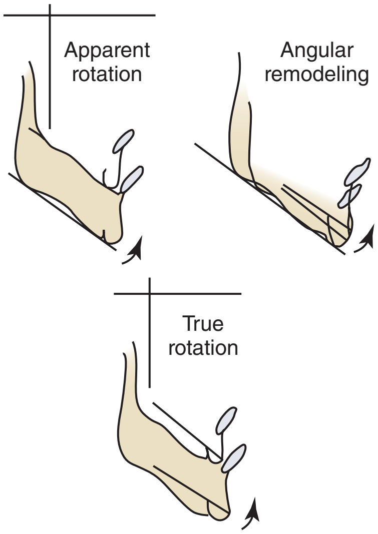


FIGURE 8-33 Percentile curves for condylar growth of females and males. *(Modified from Buschang et al.[87])*



References	Ages	deg/yr
Odegaard 1970	7-14	0.8
Lavergne and Gasson 1977	7-19	0.9
Skieller et al. 1984	Adolescents	1.0
Spady et at. 1992	Childhood	0.9
	Adolescence	0.4
Miller and Kerr, 1992	5-10	1.3
	10-15	0.8
Karlsen, 1995	6-12 (high angle)	0.7
	6-12 (low angle)	1.3
	12-15 (high angle)	0.7
	12-15 (low angle)	1.3
Wang et al. 2009	5.6-8.5	1.3
	8.5-15.5	0.7

FIGURE 8-34 True mandibular rotation (degrees per year) during childhood and adolescence.

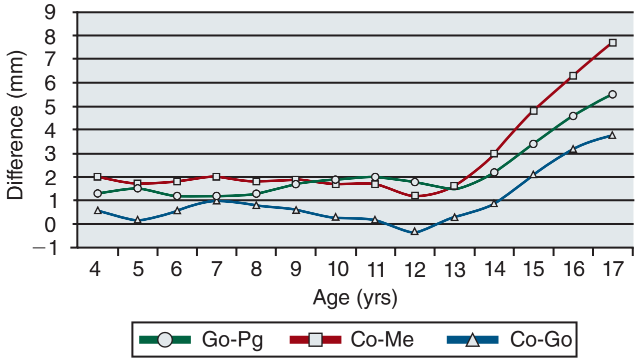


FIGURE 8-35 Sex differences (male minus female) in mandibular size. *(Adapted from Bhatia and Leighton.[40])*

resorption at gonion for every 3 mm of superior condylar growth.[88] Between 7 and 15 years of age, biantegonial and bigonial widths increase approximately 10 mm and 12 mm, respectively.[39,45] Importantly, mandibular width continues to increase throughout childhood and adolescence. While an adolescent spurt in vertical mandibular growth certainly occurs, a pronounced spurt for the anteroposterior and transverse growth has not been established.

The mandible undergoes substantial amounts of true vertical rotation and more limited, but definite, transverse rotation. While the maxilla exhibits more transverse rotation than the mandible, the mandible exhibits more vertical rotation than the maxilla. The typical pattern of rotation is forward (counterclockwise with the profile facing to the right), due to greater inferior displacements of the posterior than anterior aspects of the mandible.[89] Rates of vertical mandibular rotation have been estimated to range between 0.4 and 1.3 deg/yr, with significantly greater rates of rotation during childhood than adolescence (Figure 8-34). Although relatively few (<10%) children are "true" posterior rotators, up to 25% of adolescents have been reported to be posterior rotators.[90] Greater amounts of true mandibular rotation occur during the transition to the early mixed dentition than at any time thereafter.[91]

The mandible also rotates transversely due to greater expansion of the posterior than of the anterior aspects of the two corpii. This type of rotation has been demonstrated repeatedly in subjects with metallic implants and represents expansion of basal bone. It has also been shown that, when viewed from frontal projects, the right and left mandibular nerves are displaced laterally throughout growth. Transverse rotation is also age related, with greater amounts occurring during childhood than during adolescence. The posterior aspect of the mandible expands approximately 65% to 70% as much as the posterior maxilla expands at the midpalatal suture (see Figure 8-21).

As in the rest of the craniofacial complex, sex differences in mandibular growth are evident at the earliest ages and become pronounced during adolescence. At birth, males have significantly larger mandibles than do females.[90] Sex differences, which are greatest for overall length, followed by corpus length and ramus height, respectively, range from 0 to 2 mm between 1 and 12 years of age, when males initiate their adolescent phase of growth. Mandibular dimorphism increases to 4 to 8 mm by the end of adolescent growth phase (Figure 8-35). There are no sex differences in vertical rotation during childhood or adolescence.[90]

In summary, the mandible increases in size as a result of the combined processes of proliferation and ossification of secondary cartilage at the condyle, as well as differential formation and remodeling of bone along the entire surface of the mandible, but particularly along its superior and posterior aspects, which represent the greatest changes that occur. Because the posterior mandible generally undergoes greater inferior displacement than the anterior mandible, the mandible rotates forward. Growth of the mandible is expressed in a downward and forward growth direction relative to the rest of the cranium. In this overall pattern, the growth of the mandible follows the growth of the midface. As the midface is translated downward and forward, the mandible keeps pace in the normally growing face. Due to the geometry of the craniofacial complex, normal, coordinated growth of the jaws and a normal relationship of the associated occlusal arches require that the relative rate and amount of growth of the maxilla and mandible differ.

ARCH DEVELOPMENT, TOOTH MIGRATION, AND ERUPTION

The oral apparatus is the region of the craniofacial complex that holds the greatest potential for adaptive changes. Dental arch width and perimeter change dramatically, especially during the transitions to the early mixed and permanent dentitions.[92] Maxillary intercanine width increases approximately 3 mm during the transition to early mixed dentition and an additional 2 mm with the emergence of permanent canines (Figure 8-36). Mandibular intercanine width increases approximately 3 mm during initial transition but shows little or no change with the eruption of the permanent canines. Intermolar widths progressively increase during childhood and adolescence, approximately 4 to 5 mm for the maxilla and 2 to 3 mm for the mandible between 6 and 16 years of age (Figure 8-37). Maxillary arch depth (incisors to molars) decreases slightly during the transition to the early mixed dentition, increases 1 to 2 mm with emergence of permanent incisors, and then decreases approximately 2 mm with loss of the deciduous first and second molars. Mandibular arch depth decreases slightly during the transition to mixed dentition, maintains its dimension during most of the mixed dentition, and then decreases 2 to 3 mm with the loss of the deciduous first and second molars. Maxillary arch perimeter from first molars to first molars increases 4 to 5 mm during early mixed dentition and then decreases approximately 4 mm during late mixed dentition, resulting in only a slight overall increase between 5 and 18 years of age (Figure 8-38). Mandibular arch perimeter, from first molar to first molar, on the other hand, increases approximately 2 mm during early mixed dentition and decreases 4 to 6 mm during late mixed dentition, resulting in overall decreases of 3.5 and 4.5 mm in males and females, respectively.

Perhaps most important from a clinical perspective, the teeth continue to migrate and erupt throughout childhood and adolescence, even after they have attained functional occlusion. The posteruptive movements of teeth are directly related to the spaces created by growth displacements and movements of other teeth. Dentoalveolar compensation is the mechanism that coordinates their eruption and migration relative to their jaw bases; it maintains the relationships of teeth within and between the upper and lower dental arches. Dentoalveolar compensation depends on a normal eruptive system, dental

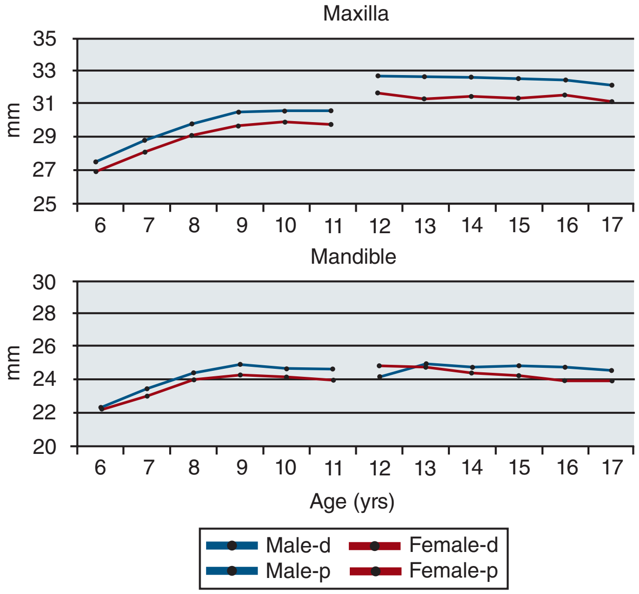


FIGURE 8-36 Maxillary and mandibular intercanine widths of males and females based on measurements taken from the deciduous (*d*) and permanent (*p*) canines. *(From data provided by Moyers et al.[93])*

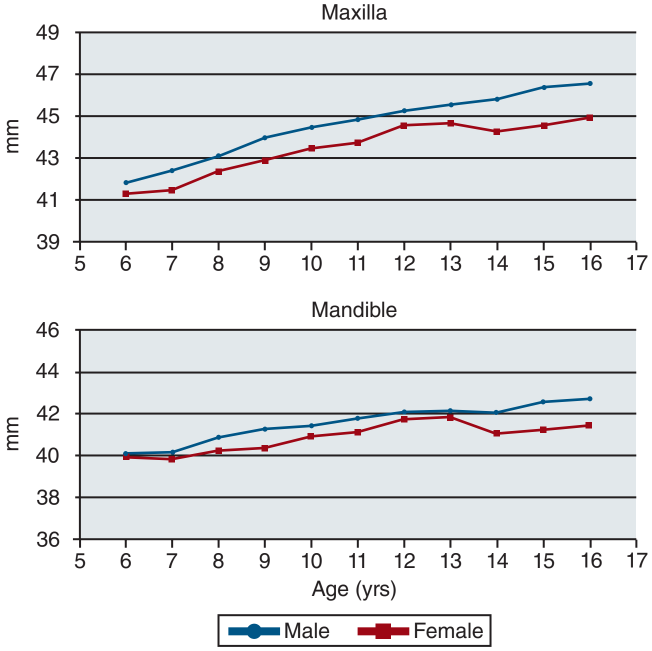


FIGURE 8-37 Maxillary intercanine width of males and females based on measurements taken from the deciduous (*d*) and permanent (*p*) canines. *(From data provided by Moyers et al.[93])*

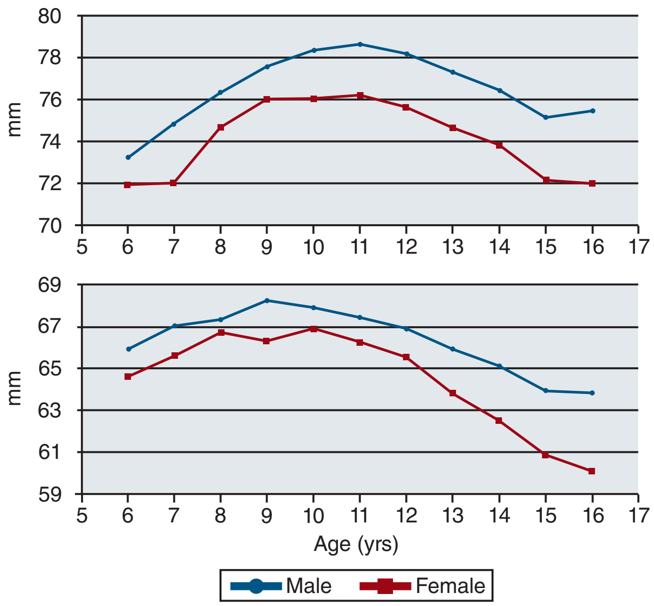


FIGURE 8-38 Maxillary and mandibular arch perimeter of males and females. *(From data provided by Moyers et al.[93])*

equilibrium, and influences of neighboring teeth.[94] During childhood, the maxillary incisor drifts anteriorly at a greater rate than the maxillary molar (0.8 vs. 0.6 mm/yr, respectively), which accounts for the arch depth increases evident between 6 and 12 years of age (Figure 8-39). In contrast, the mandibular molars drift anteriorly at a slightly greater rate than the incisors, resulting in a net loss of arch depth. Between 10 and 15 years of age, the molars (0.5 to 0.7 mm/yr) show significantly greater amounts of anterior drift than the incisors (0.3 mm/yr).

Substantial amounts of eruption occur throughout growth. During childhood, the maxillary first molars and incisors erupt at a rate of approximately 1.0 mm/yr, while their mandibular counterparts erupt at a rate of approximately 0.5 mm/yr (Figure 8-40). During adolescence, the maxillary molars and incisors erupt at rates of 1.2 to 1.4 mm/yr and 0.9 mm/yr, respectively. The mandibular molars and incisors erupt at a rate of 0.5 to 0.9 mm/yr, with little or no differences between incisor and molar eruption. The amounts of eruption that occur

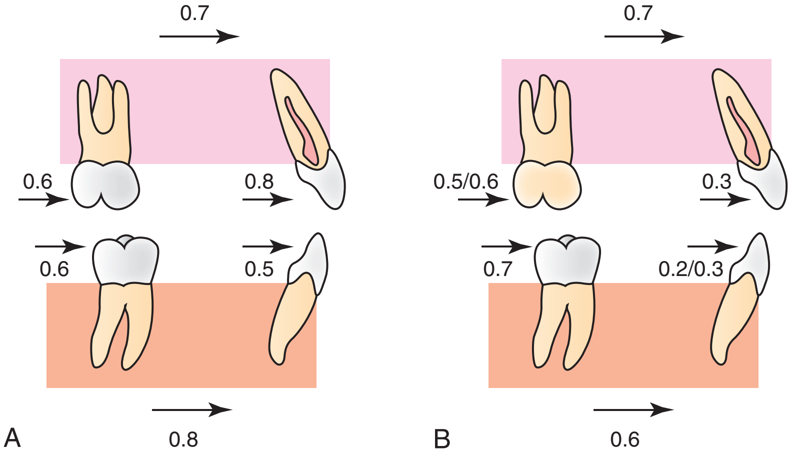


FIGURE 8-39 Approximate maxillary and mandibular AP displacements and tooth migration (mm/yr) during **(A)** childhood and **(B)** adolescence (female/male).

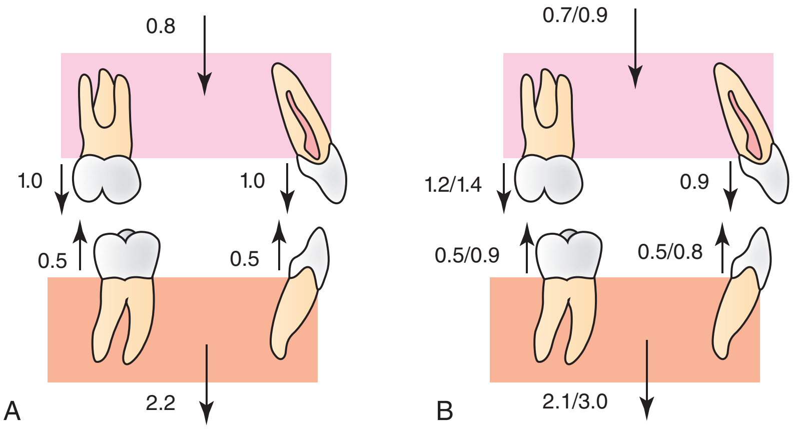


FIGURE 8-40 Approximate maxillary and mandibular vertical displacements (mm/yr) and tooth eruption during **(A)** childhood and **(B)** adolescence (female/male).

are associated closely with the inferior displacements of the midface and, especially, the mandible.

During childhood, there is little or no evidence of sexual dimorphism in the migration and eruption of teeth. In contrast, there is a relatively high degree of dimorphism during adolescence in mandibular eruption, with boys showing almost twice as much eruption as girls. The maxillary teeth show only limited sex differences, pertaining primarily to the molars.

POSTNATAL INTERRELATIONSHIPS DURING CRANIOFACIAL GROWTH

Postnatal craniofacial growth follows a gradient of relative growth that ranges between the neural and general somatic patterns. Vertical growth and remodeling of the splanchnocranium, as well as dental eruption, exhibit mid-childhood and adolescence spurts. Girls and boys enter the adolescent phase at approximately 10 and 12 years, respectively, and attain peak adolescent growth velocities at approximately 12 and 14 years of age. The mid-childhood growth spurt, which occurs around 7 to 8 years of age, is another period of intense growth, but it does not occur in all individuals. Anteroposterior growth and tooth migration, which do not exhibit mid-childhood or adolescent spurts, change more or less regularly—except for the accelerated migration associated with the loss of teeth—throughout childhood and adolescence.

Generally, most displacements and rotations of the maxillomandibular complex are controlled epigenetically through growth of the chondrocranium, soft tissue growth, and expansion of the oronasal capsule. The cartilaginous growth centers play a particularly important role in the primary displacement of the chondrocranium, as well as in the secondary displacement of the splanchnocranium. The anterior displacement of the midface has been associated with growth of the anterior cranial base and expansion of the anterior cranial fossa; mandibular displacements are more closely associated with growth of the posterior cranial base and middle cranial fossa. Anteroposterior length changes of the anterior cranial base, measured from sella to foramen cecum, coincide closely with expansion of the frontal lobes and growth at the sphenoethmoidal synchondrosis. Angular changes of the cranial base have been associated with growth gradients within the synchondroses, complex interactions with the growth of the brain, as well as facial growth. The cranial base angle decreases due to greater chondrogenesis in the superior than in the inferior aspects of the sphenoethmodial and spheno-occipital synchondroses.[95] Changes in cranial base angulation also appear to be related to changes in brain size, especially to the dramatic changes that occur during the first 2 postnatal years.[96]

Cranial base growth influences the displacement and rotation of the splanchnocranium. Growth of the posterior cranial base (i.e. spheno-occipital synchondrosis) is directly related to inferior and posterior displacements of the glenoid fossa; growth of the anterior cranial base is associated with midfacial displacement. Consequently, cranial base growth changes partially explain individual and population differences in anteroposterior skeletal relationships. While some have reported little or no effects, most studies show that individuals with larger cranial base angles and/or larger anterior and posterior cranial base lengths tend to be retrognathic (i.e., Class II), whereas those with the smaller lengths and angles tend to be prognathic (i.e., Class III).

Structures within the midfacial complex also affect its displacement and rotation. Growth of the eyeball is associated with both the anterior and lateral displacements of the midface; enucleation of the eyeball during growth results in deficiencies in the anterior and lateral growth of the midface.[97] The nasal septum also plays important roles in nasomaxillary growth, displacement, and rotation. However, while the anterior cranial fossa, cranial base, eyeball, and nasal septum play an important role in the early displacement and rotation of the midface, their growth potentials are limited after 7 to 8 years of age. Soft tissue growth and other factors leading to the expansion of the oronasal capsule are relatively more important in explaining the midfacial rotation and displacement during later childhood and adolescence.

In turn, mandibular displacement and rotation are greatly influenced by midfacial displacement and rotation, growth of the posterior cranial base, soft tissue growth, and expansion of the oronasal capsule. Posture also has a profound effect on mandibular growth and remodeling. There is also a direct relationship between the true rotation of the maxilla and mandible. Both jaws usually rotate forward; individuals showing greater amount of forward rotation of the maxillary also tend to show greater forward rotation of the mandible (Figure 8-41). Midfacial growth and the associated changes in the position of the maxillary dentition are also thought to play an important role in mandibular growth

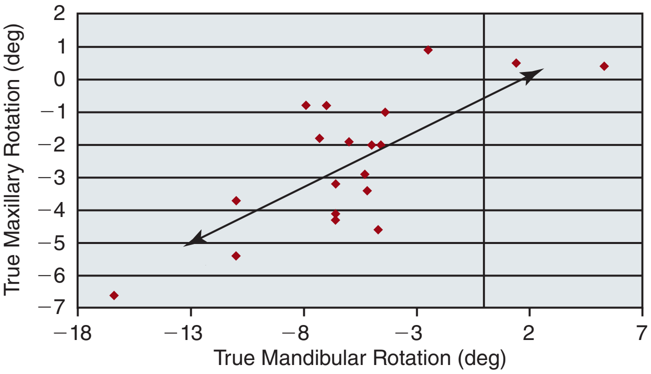


FIGURE 8-41 Relationship of true mandibular and true maxillary rotation ($r = 0.75$). *(Based on data provided by Björk and Skieller.[89])*

displacements.[65,75,98] Major insults to maxillary growth can inhibit mandibular growth.[99] Cranial growth disturbances can also influence mandibular growth indirectly through their effects on the midface, as well as on the positional changes of the glenoid fossa, especially during infancy and early childhood. For example, it has been shown that craniosynostosis, if left untreated for a sufficiently long period of time, can produce significant asymmetry of the mandible.

The anterior and, especially, inferior displacements of the maxilla and mandible have direct effects on the growth at the sutures, condylar growth, remodeling patterns, dental eruption, and dental migration. Although there is an upper threshold, the amount of bony apposition that occurs at sutures is directly related to the amount of sutural separation that occurs. It has been shown that larger forces produce greater sutural separation, which in turn results in greater amounts of sutural bone formation (Figure 8-42). Such growth potential is essential during periods of greater sutural separation, such as during infancy and adolescence, which require concomitantly greater bone formation. The condyle also undergoes a growth spurt that closely coincides with the increased rates of inferior displacement of the mandible that occur during adolescence.[101] Because the remodeling patterns of the mandible are directly related to the amounts of vertical and horizontal displacement that take place,[102] individuals with greater inferior displacement show greater superior drift of bone along the entire surface of the ramus (i.e., greater apposition superiorly and greater resorption along the lower border) than do individuals who undergo less inferior displacement. Due to the close association between mandibular displacement and rotation, individuals showing greater or lesser amounts of anterior displacement of the mandible tend to exhibit lesser or greater amounts of posterior drift of the superior aspect of the ramus, respectively. The amounts of inferior displacement of the mandible that occur are also positively related to the amount of eruption that occurs, especially of the posterior teeth (Figure 8-43). Importantly, it is the displacement that determines the amounts of eruption and supraeruption that occur during growth, rather than vice versa. Displacements of the mandible also influence the anteroposterior compensations of the teeth. Individuals showing relatively greater anterior displacement of the mandible than maxilla tend to exhibit greater mesial displacement of the maxillary molars and counterclockwise rotation of the occlusal plane; those who undergo relatively greater anterior maxillary displacements display greater mesial displacement of the mandibular molars and minimal mesial displacement of maxillary molars.[103]

The morphologic correlates with true rotation are numerous and hold important clinical implications.[104] Vertical rotation has been directly related to changes in tooth position, with true forward rotators showing greater amounts of lower incisor proclination during eruption; backward rotators show retroclination of the incisors and loss of arch space. Rotation is also related to the remodeling pattern that occurs on the lower mandibular border; subjects who undergo the greatest amounts of true forward rotation also exhibit the greatest amounts of posterior resorption and anterior bony deposition (Figure 8-44). Ramus remodeling in general depends on the rotational pattern of the mandible. Individuals who undergo greater amounts of true forward rotation also exhibit greater amounts of condylar growth, oriented in a more superior-anterior direction (Figure 8-45). Perhaps the most important clinical correlate is the relationship between true rotation and chin position. True rotation of the mandible explains more of the individual variation in chin position than condylar growth or changes in glenoid fossa position.

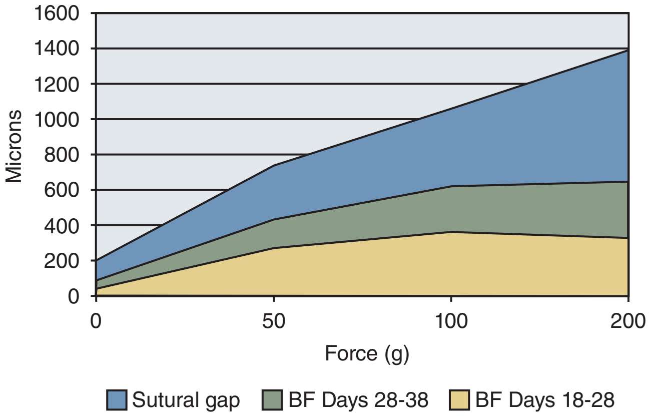


FIGURE 8-42 Relationships of bone formation (*BF*), sutural gap width, and amounts of force applied to separate sutures. *(Adapted from Liu et al.[100])*

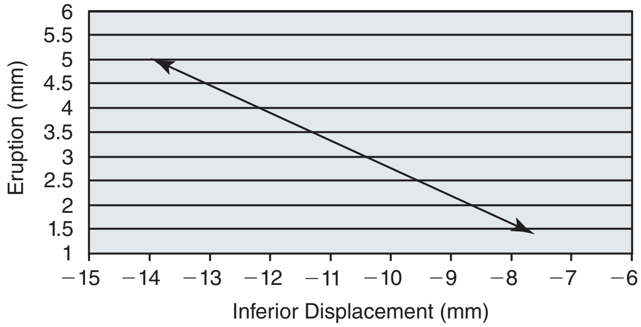


FIGURE 8-43 Relationship between the eruption of the mandibular molars and inferior displacement of the mandible.

SIGNIFICANCE OF UNDERSTANDING CRANIOFACIAL GROWTH FOR ORTHODONTICS

To be most effective as clinicians, it is essential that orthodontists understand the development, growth, and adaptive potentials of the craniofacial structures. Along with orthodontic biomechanics, knowledge of how the

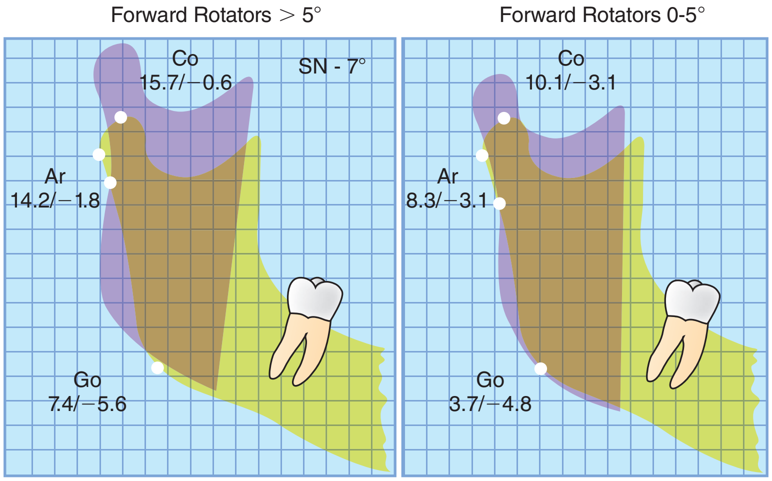


FIGURE 8-44 Vertical/horizontal (mm) remodeling changes of the individuals showing greater than 5 degrees of true forward rotation, compared with those showing 0- to 5-mm true forward rotation.

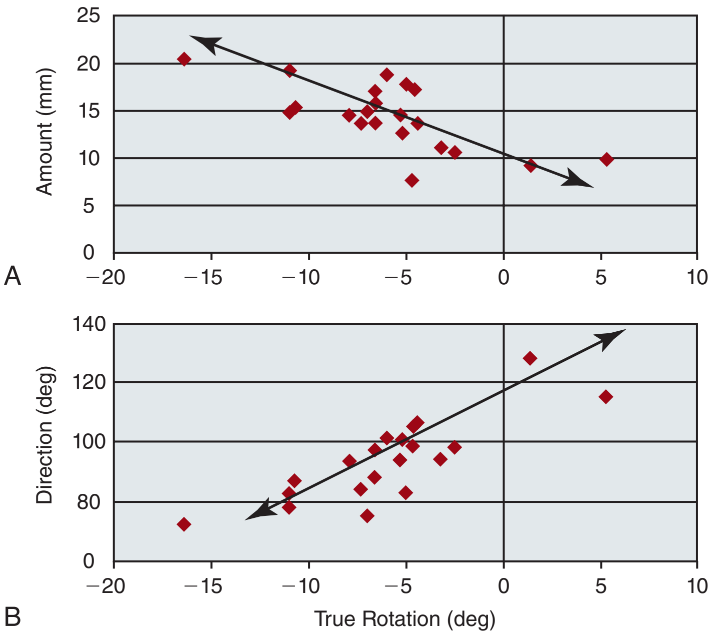


FIGURE 8-45 Relationships of true mandibular rotation and **(A)** the amount of condylar growth and **(B)** the direction of condylar growth. *(Data from Björk and Skieller.[89])*

craniofacial complex develops and grows provides the foundation for understanding the etiology of the various dental and skeletal malocclusions, the best of all possible treatment approaches, and how patients might be expected to respond after treatment. A thorough understanding of growth provides the basis for knowing which craniofacial components might be expected to respond to a stress and how great the response might be expected to be. Because a structure's response potential to stress is directly related to its relative growth potential, and the vertical aspects of the mandible have the greatest relative growth potential, it follows that skeletal malocclusions might be expected to relate to vertical mandibular growth. Class II malocclusion, which is the predominate form of skeletal malocclusion, pertains primarily to the mandible.[105,106] These individuals are often retrognathic due to limited true forward rotation of the mandible, which is in turn related to deficient inferior growth displacement of the posterior mandible and/or excessive inferior displacement of the anterior aspect of the mandible.

Knowledge of growth is also important because, whenever possible, orthodontists should try to mimic growth when planning treatment. An understanding of growth provides the biological limits within which treatments can be performed. As previously indicated, the splanchnocranium is made up of intramembranous bone and is predominantly under epigenetic and environmental control. It is programmed to adapt, and adaptation should be expected whenever it is stressed. The biological system cannot distinguish between the stresses imposed by the orthodontist versus those imposed during normal growth; it simply responds based on its various potentials. Continuing with the previous example, individuals who exhibit good growth patterns tend to be true forward rotators with condyles that grow in a more anterior direction. Based on this knowledge, hyperdivergent retrognathnic patients would be best served by treatments that focus on rotating the mandible, rather than trying to stimulate or redirect the growth of the condyles in a posterior direction.[107]

Finally, an understanding of growth makes it possible to estimate morphologic changes that might be expected to occur after orthodontic treatment. Knowing how an individual patient grew before treatment provides considerable information about how he or she might be expected to grow after treatment. As previously indicated, knowing how the maxilla and mandible have been rotated and/or displaced during treatment provides an understanding of the remodeling and consequent shape changes that might be expected to occur after treatment. The aforementioned relationships also suggest that vertical growth after treatment might be problematic in terms of post-treatment crowding, due to its relationship with eruption of teeth. It has, in fact, been shown that the only good predictors of crowding of the mandibular incisor, both after treatment and without treatment, are the inferior displacement of the mandible and superior eruption of the incisors.[96]

As understanding of craniofacial development, growth, and adaptation continues to improve in the future, orthodontists can look forward to even more therapeutic advances that can be used to influence growth and post-treatment stability. This understanding will facilitate greater clinical control of changes in the craniofacial complex due to the normal growth process and in compensatory adaptation of tissues after treatment. Understanding normal craniofacial growth and especially that of the complex network of underlying molecular factors responsible for craniofacial growth and treatment will also be of immeasurable benefit in assisting the orthodontist in understanding what may or may not be possible, not only with respect to diagnosing a patient's underlying abnormality but also in determining the best treatment approach for its correction.[76,108]

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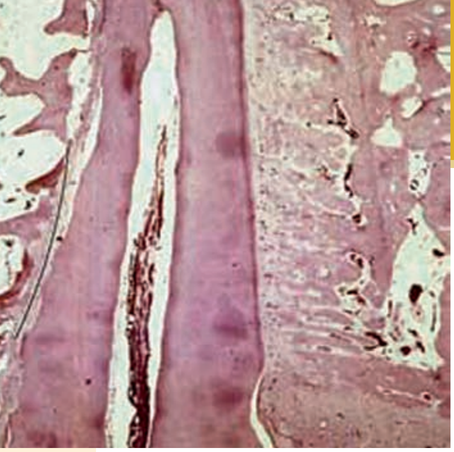

CHAPTER 9

Tissue Reactions in Orthodontics

Birgit Thilander

OUTLINE

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Summary

Orthodontic treatment today comprises a wealth of removable and fixed appliances, sometimes in combination with extraoral ones. Despite differences in design, they all involve the use and control of forces acting on the teeth and adjacent structures. The principal changes from such forces are seen within the dentoalveolar system, resulting in *tooth movements*. Other structures, such as sutures and the temporomandibular joint (TMJ) area, can also be influenced by means of *dentofacial orthopedics*. An optimal orthodontic force intends to induce a maximal cellular response and to establish stability of the tissue, whereas an unfavorable force does not result in a precise biological response and may initiate adverse tissue reactions.

Although a considerable number of studies based on human material illustrate the *quantitative* changes occurring during orthodontic treatment (e.g., cephalometry), the main evidence for the *qualitative* histologic responses to orthodontic treatment comes from experimental studies on animals. Human material has been used to study orthodontically induced reactions in the supporting structures of teeth intended for extraction, but animal material must be used to study basal changes. However, conclusions based on such results should be viewed with caution because species may differ in terms of basic morphology, growth pattern, turnover rate, and speed of tissue reaction. Moreover, animal experiments involve the alteration of normal structures, whereas dentofacial orthopaedic measures are aimed at correcting already existing anomalies.

The main purpose of this chapter is not to discuss appliances but instead to focus on tissue reactions in periodontium, sutures, and the TMJ region during the active phase of treatment as well as during the retention and postretention periods.

TOOTH-SUPPORTING TISSUES

During tooth movement, changes in the periodontium occur, depending on magnitude, direction, and duration of the force applied, as well as the age of the orthodontically treated patient. Tooth movement is a complicated process, requiring changes in the gingiva, periodontal ligament, root cementum, and alveolar bone with their

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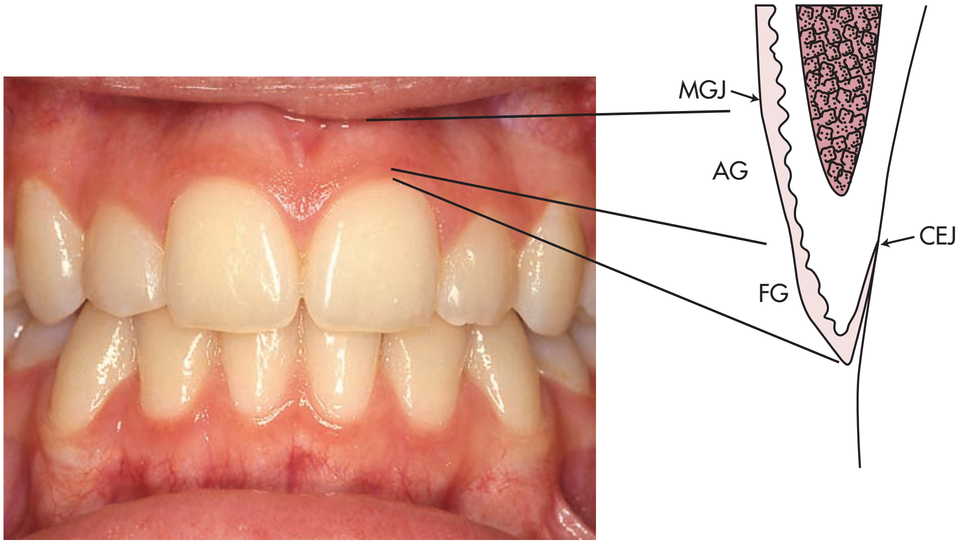

FIGURE 9-1 Macroscopic anatomy of the gingival showing free gingiva (FG), attached gingiva (AG), mucogingival junction (MGJ), cementoenamel junction (CEJ).

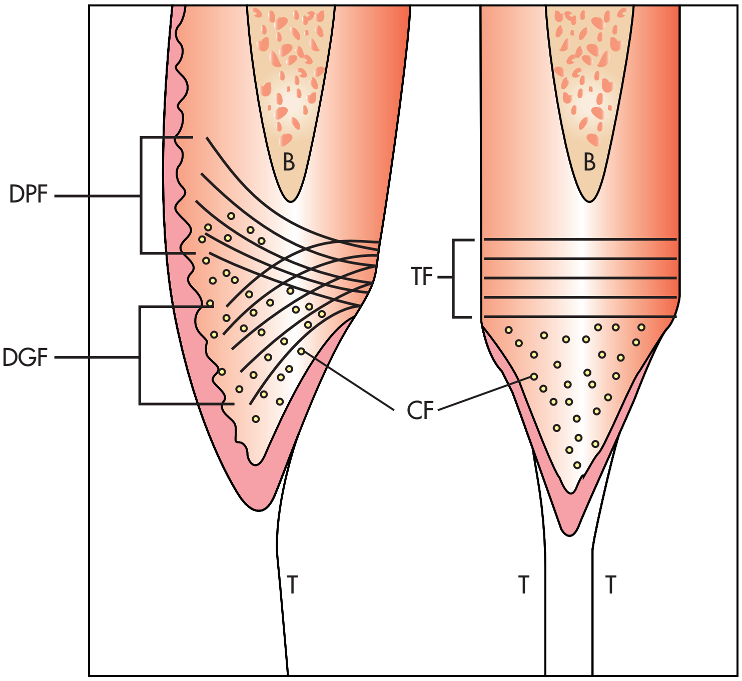

FIGURE 9-2 Drawings (vestibular and interdental aspects of the teeth) illustrating the different collagen bundles in the gingival showing circular fibers (CF), dentogingival fibers (DGF), dentoperiosteal fibers (DPF), and transseptal fibers (TF). (Adapted from Lindhe J, Karring T: The anatomy of the periodontium. *(From Lindhe J, editor:* Textbook of clinical periodontology, *Copenhagen, 1989, Munksgaard.)*

differences in cell population and remodeling capacity. This chapter, therefore, includes a brief description of the normal periodontium.[1]

Gingiva

The gingiva is differentiated into the free and attached gingiva (Figure 9-1). In a clinically healthy condition, the *free gingiva* is in close contact with the enamel surface, and its margin is located 0.5 to 2 mm coronal to the cementoenamel junction after completed tooth eruption. The *attached gingiva* is firmly attached to the underlying alveolar bone and cementum by connective tissue fibers and is therefore comparatively immobile in relation to the underlying tissue.

The predominant component of the gingiva is the connective tissue, which consists of collagen fibers, fibroblasts, vessels, nerves, and matrix. The *fibroblast* is engaged in the production of various types of fibers but is also instrumental in the synthesis of the connective tissue matrix. The *collagen fibers* are bundles of collagen fibrils with a distinct orientation. They provide the resilience and tone necessary for maintaining its architectural form and the integrity of the dentogingival attachment. They are usually divided into the following groups (Figure 9-2):

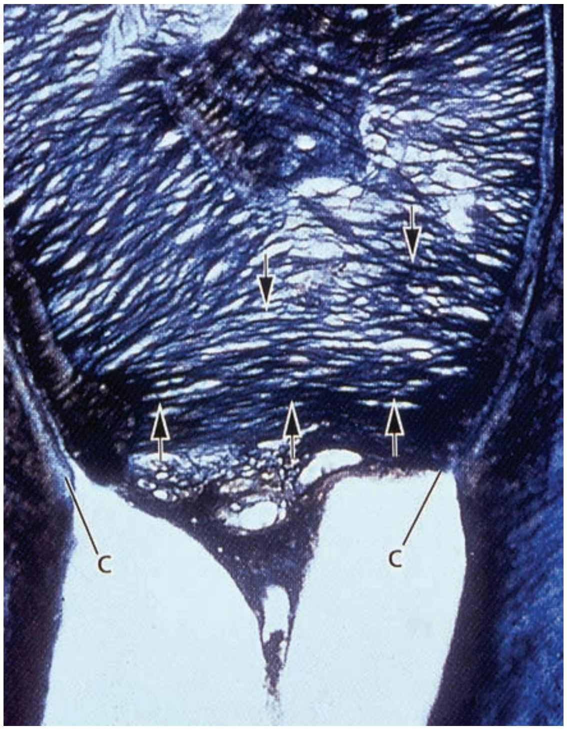

FIGURE 9-3 A histologic section illustrating the orientation of transseptal fiber bundles *(arrows)* in the supra-alveolar portion of the interdental area. They also connect the cementum *(C)*. *(From Lindhe J, Karring T: The anatomy of the periodontum. In Lindhe J, editor:* Textbook of clinical periodontology, *ed 4, Copenhagen, 2003, Blackwell Munksgaard. With permission.)*

- *Circular fibers* run in the free gingiva and encircle the tooth.
- *Dentogingival fibers* are embedded in the cementum of the supraalveolar portion of the root and project from the cementum in a fanlike configuration into the free gingival tissue.
- *Dentoperiosteal fibers* are embedded in the same portion of the cementum as the dentogingival fibers but terminate in the tissue of the attached gingiva.
- *Transseptal fibers* run straight across the interdental septum and are embedded in the cementum of adjacent teeth (Figure 9-3).

Periodontal Ligament

The periodontal ligament (PDL), about 0.25 mm wide, is the soft, richly vascular and cellular connective tissue that surrounds the roots of the teeth and joins the root cementum with the lamina dura or the alveolar bone proper. In the coronal direction, the PDL is continuous with the lamina propria of the gingiva and is separated from the gingiva by the collagen fiber bundles, which connect the alveolar bone crest with the root (the alveolar crest fibers).

The PDL and the root cementum develop from the follicle, which surrounds the tooth bud. The true periodontal fibers, *the principal fibers*, develop along with the eruption of the tooth. First, fine fibrils arise from the root cementum and the bone surface and fuse as they contact. Later on, the number and thickness of fibers increase. The orientation of the collagen fiber bundles alters continuously during tooth eruption. When the tooth has reached contact in occlusion and is functioning properly, they associate with the following well-oriented groups: *alveolar crest fibers* and *horizontal, oblique, apical, and interradicular fibers* (Figure 9-4). The individual bundles have a slightly wavy course, which allows the tooth to move within its socket (physiologic mobility). The presence of a PDL makes it possible to distribute and resorb the forces elicited during mastication and is essential for movement of the teeth in orthodontic treatment.

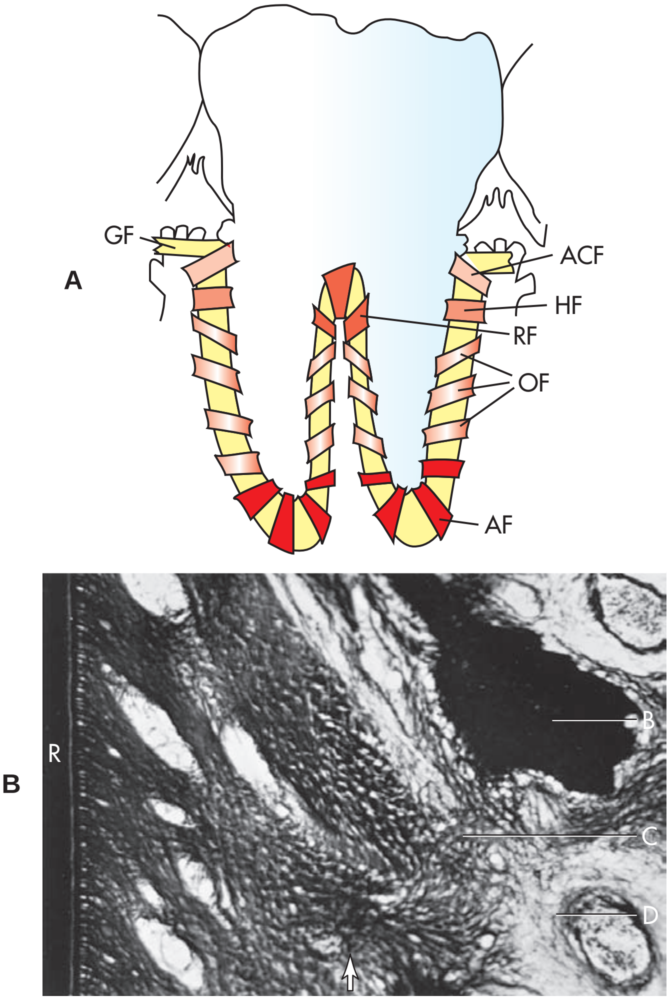

FIGURE 9-4 **A,** The PDL fibers: Alveolar-crest fibers *(ACF)*, apical fibers *(AF)*, gingival fibers *(GF)*, horizontal fibers *(HF)*, oblique fibers *(OF)*, and interradicular fibers *(RF)*. **B,** The periodontal fibers interlace with the fibrous matrix of the bone, forming a fibrous system. In a physiologic state this system appears relaxed. *R*, Root surface; *B*, remaining calcified bone in which the fiber arrangement cannot be seen; *C*, Sharpey's fibers interlacing with fibers of the bone; *D*, loose fibrous tissue around a capillary *(arrow)*.

The fibrils of the PDL are embedded in a ground substance with connective tissue polysaccharides

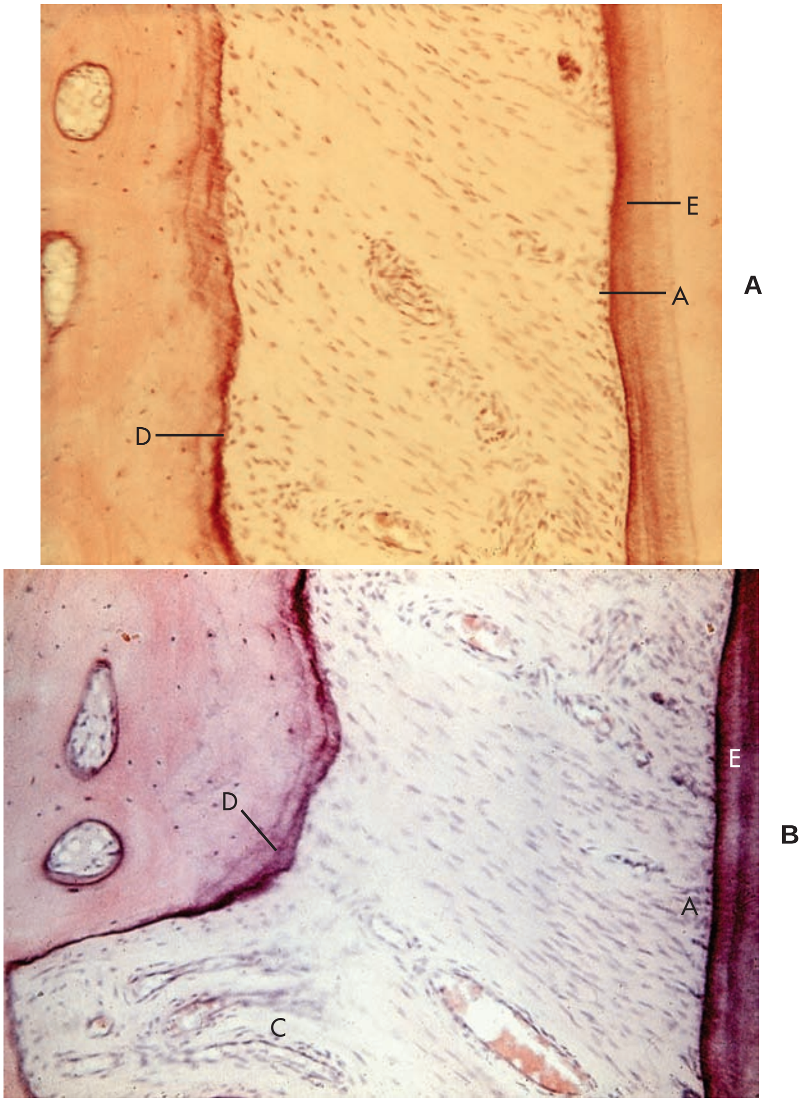

FIGURE 9-5 Area from the alveolar crest of **(A)** a 39-year-old patient and **(B)** a 22-year-old patient. *A,* Chain of cementoblasts along a thick layer of cementum. *C,* Widened capillary in a cleft, where bone resorption may start during the initial stage of tooth movement. *D,* Darkly stained surface line containing connective tissue polysaccharides. Note the absence of osteoblasts along the bone surface. *E,* Embedded principal fibers.

(glycosaminoglycans), which vary with age. The tissue response to orthodontic forces, including cell mobilization and conversion of collagen fibers, is considerably slower in older individuals than in children and adolescents. The ground substance has a more rapid turnover than the collagen fibers.

During physiologic conditions, collagen turnover in the PDL is much higher than that in most other tissues (e.g., twice as high as that of the gingiva). The high turnover has been attributed to the fact that forces on the PDL are multidirectional, having vertical and horizontal components. The lower collagen turnover in the gingiva may result from the lowered functional stress as the transseptal fibers function in a manner similar to tendons, providing firm anchorage of the tooth.

Root Cementum

The root cementum is a specialized mineralized tissue covering the root surface and has many features in common with bone tissue. However, the cementum contains no blood vessels, has no innervation, does not undergo physiologic resorption or remodeling, and is characterized by continuing deposition throughout life. The cementum attaches the PDL fibers to the root and contributes to the process of repair after damage to the root surface (e.g., during orthodontic treatment).

During root formation a *primary cementum* is formed. After tooth eruption and in response to functional demands, a *secondary cementum* is formed that, in contrast to the primary cementum, contains cells. During the continuous formation of the primary cementum, portions of the principal fibers in the PDL adjacent to the root become embedded and mineralized (Figure 9-5). The Sharpey fibers in the cementum should be regarded as a direct continuation of the collagen fibers in the PDL.

Alveolar Bone

The alveolar bone is covered with the *periosteum*, which is differentiated from the surrounding connective

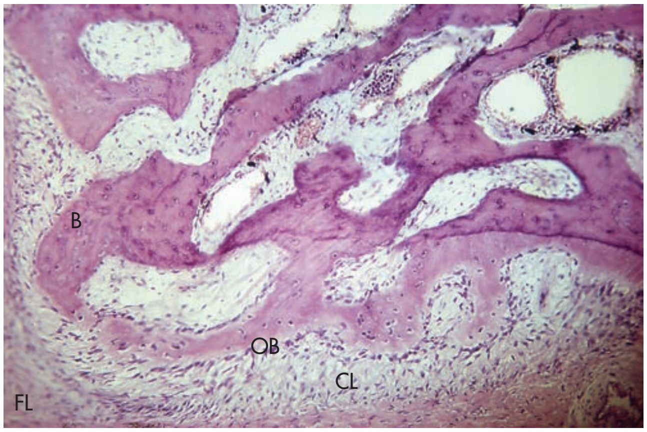

FIGURE 9-6 Photomicrograph of intramembranous bone (*B*) covered with periosteum. *OB,* Osteoblasts; *CL,* cambium layer; *FL,* fibrous layer.

tissue (Figure 9-6). The contiguous mesenchymal cells acquire the character of osteoblasts. The matrix-producing and proliferating cells in the cambium layer are subject to mechanical influence. Whenever the pressure exceeds a certain threshold, reducing the blood supply to these cells, osteogenesis ceases. However, if the periosteum is exposed to tension, it responds with bone deposition. Therefore, the periosteum continues to function as an osteogenic zone throughout life, although its regenerative capacity is extremely high in the young child.

The alveolar process forms and supports the sockets of the teeth. It consists of dense outer *cortical bone* plates with varying amounts of spongy or *cancellous bone* between them. The thickness of the cortical laminae varies in different locations (Figure 9-7). The cancellous bone contains bone trabeculae, the architecture of which are partly genetically determined and partly the result of forces to which teeth are exposed during function or orthodontic treatment.

The alveolar bone is renewed constantly in response to functional demands. Bone-forming *osteoblasts* and *osteoclasts*, cells involved in resorption (Figure 9-8), are responsible for this remodeling process. These cells are present on the socket walls toward the periodontal membrane, on the inside of the cortical bone toward the marrow spaces, and on the surface of the bone trabeculae in cancellous bone. The osteoblasts produce *osteoid*, consisting of collagen fibers and a matrix that contains mainly proteoglycans and glycoproteins. Osteoid is found on all bone surfaces where new bone is deposited (Figure 9-9, *A*), and unlike calcified bone is not attacked by osteoclasts. When this bone matrix undergoes mineralization by deposition of minerals, such as calcium and phosphate, it converts into *bundle bone*. Cells and fiber bundles are incorporated in bundle bone during its life cycle. When bundle bone has reached a certain thickness

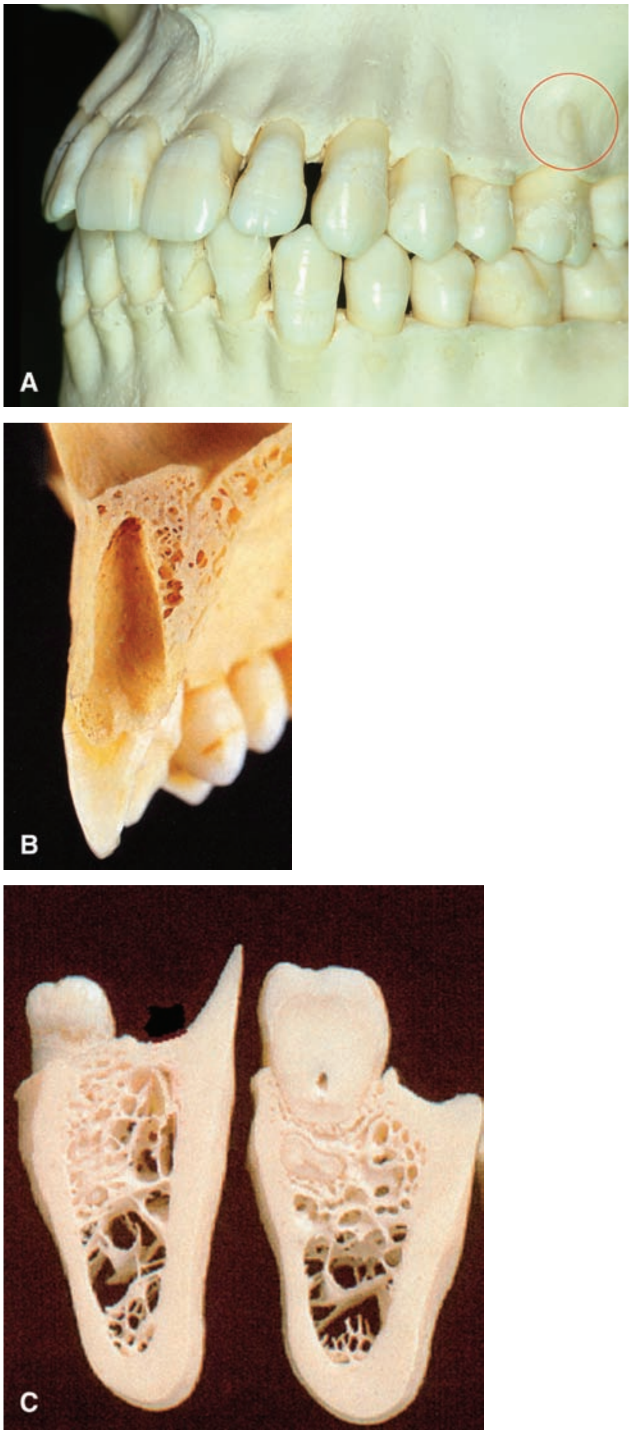

FIGURE 9-7 **A,** Cranium showing the various thicknesses of the cortical laminae in different locations of the alveolar processes. Note the thin bone plate at the buccal aspects of the mandibular incisor area and the teeth in the maxilla, resulting in fenestration (*circle*). **B** and **C,** Dried bone specimen from the incisor area of the maxilla and different areas of the mandible showing cancellous bone and outer cortical plate.

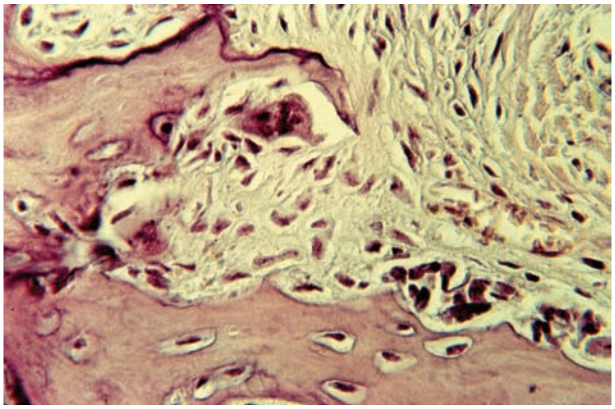

FIGURE 9-8 Photomicrograph of intramembranous bone with osteoclasts, involved in resorption.

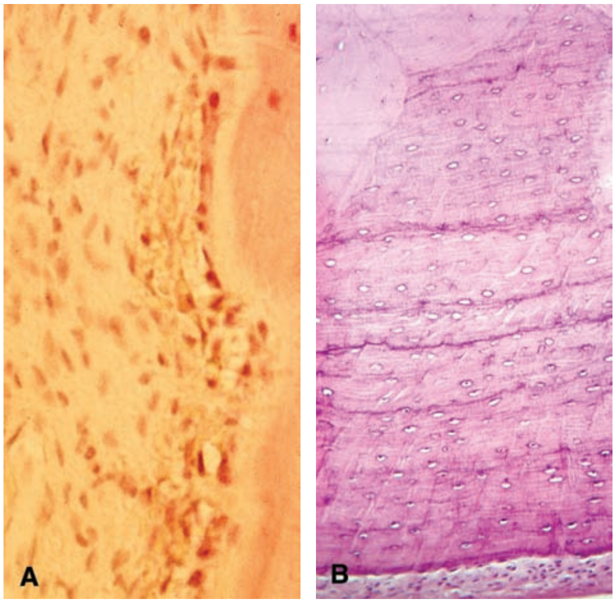

FIGURE 9-9 **A,** Osteoid is found on all bone surfaces, where new bone is deposited. **B,** Bundle bone reorganized into lamellated bone.

and maturity, parts of it are reorganized into *lamellated bone* (Figure 9-9, *B*).

The type of bone through which the tooth is displaced must be considered in the orthodontic treatment plan. Tooth movements in a mesial or distal direction displace the roots through the spongiosa of the alveolar bone. When a tooth is moved into the reorganizing alveolus of a newly extracted tooth, remodeling is rapid because of the many differentiating cells present and the limited amount of bone to be resorbed. On the contrary, movement of a tooth labially or lingually into the thin cortical plates should be undertaken with a high degree of caution, especially in adult patients, to avoid iatrogenic responses.

PHYSIOLOGIC TOOTH MIGRATION

Tissue reactions in the tooth-supporting tissues are connected not only with orthodontic treatment but also with eruption of the teeth and development of the occlusion. The development of the dentition is a complex process and depends on many variables, which by no means always combine harmoniously.

The *eruption of teeth* to occlusal contact is an event that covers only a short period in life. However, the teeth and their supporting tissues have a lifelong ability to adapt to functional demands and hence drift through the alveolar process, a phenomenon called *physiologic tooth migration*. Also well known clinically is that any change in the equilibrium of occlusal pressure, such as loss of a neighboring or antagonistic tooth, may induce further tooth movement.

The tissue reaction that occurs during physiologic tooth migration is a normal function of the supporting structures. This was pointed out for the first time by Stein and Weinmann,[2] who observed that the molars in adults gradually migrate in a mesial direction. When the teeth migrate, they bring the supra-alveolar fiber system with them. Such movement implies remodeling of the PDL and alveolar bone. The turnover rate of the PDL is not uniform throughout the ligament, the cells being more active on the bone side than near the root cementum.

The remodeling processes that occur during the physiologic migration are illustrated in Figures 9-10 and 9-11. Osteoclasts are seen in scattered lacunae associated with the *resorptive surface* along the alveolar bone wall, toward which the tooth is moving; the number of cells is more numerous when tooth migration is rapid. The alveolar bone wall from which the tooth is moving away (*depository side*) is characterized by osteoblasts depositing nonmineralized osteoid, which later mineralizes in the deeper layer. Specific staining techniques reveal how the older fibers of the PDL are surrounded by newly deposited bone matrix and become embedded in bone. Simultaneously, new collagen fibrils are produced on the bone surface.

A slow apposition occurs on the cementum surface throughout life, a fact that is of great importance for the resorptive mechanism in the bone and cementum. The unmineralized precementum layer has special importance as a resorption-resistant “coating” layer, thus protecting the root surface during the physiologic migration.

Because considerable changes in tooth position occur without any orthodontic invention, knowledge of periodontal remodeling during physiologic tooth migration is of utmost importance during the postretention period.

ORTHODONTIC TOOTH MOVEMENTS

Basically, no great difference exists between the tissue reactions observed in physiologic tooth migration and those observed in orthodontic tooth movement. Because the teeth are moved more rapidly during treatment, the tissue changes elicited by orthodontic forces are more significant and extensive.[3] The knowledge of the reactions of the supporting structures in orthodontic treatment is still incomplete because histologic techniques used today can provide only limited information on the behavior of the ground substance, blood, and tissue fluids. However, application of a force on the crown of the tooth leads to a response in its surrounding tissues, resulting in an orthodontic tooth movement, which depends on type, magnitude, and duration of the force. Thus, knowledge of several fundamental mechanical concepts is necessary to understand in clinical orthodontics and is discussed in Chapter 11. Hence, only a brief survey of biomechanical principles is given here, factors of importance for understanding the tissue reaction in supporting tissues.

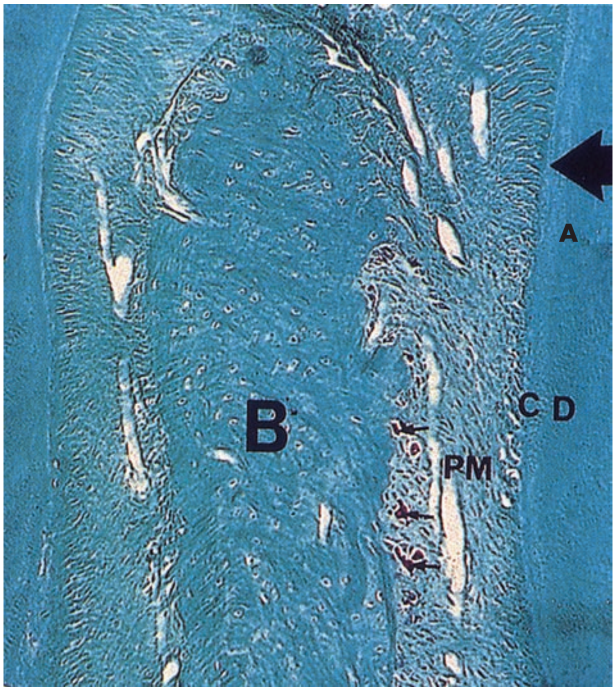

FIGURE 9-10 Physiologic migration *(PM)* of first rat molar *(A)* in direction of the arrows. Scattered osteoclasts, stained red, adjacent to the alveolar bone *(B)*. *(From Brudvik P, Rygh P: The initial phase of orthodontic root resorption incident to local compression of the periodontal ligament,* Eur J Orthod *15:249, 1993.)*

Orthodontic Forces and Tissue Reaction

Orthodontic forces comprise those that are meant to act on the PDL and alveolar process, whereas orthopedic forces are more powerful and act on the basal parts of the jaws. The decisive variables regarding these forces at the cellular level are application, magnitude, duration, and direction of force.[4]

Two different types of applied force exist: *continuous* and *intermittent* (Figure 9-12). Modern fixed appliance systems are based on light continuous forces from the archwire. However, a continuous force may be interrupted after a limited period. An example of such an *interrupted continuous* force is when it is no longer acting and hence has to be reactivated. In clinical orthodontics, an interrupted tooth movement may have certain advantages as the tissues are given ample time for reorganization, which is favorable for further tissue changes when the force is again activated. An *intermittent* force acts during a short period and is induced primarily by removable appliances, especially functional appliances.

The *magnitude* and duration of forces are important for the tissue response. Reactions in PDL to heavy, continuous loads (50 centiNewtons [cN]) in experimental

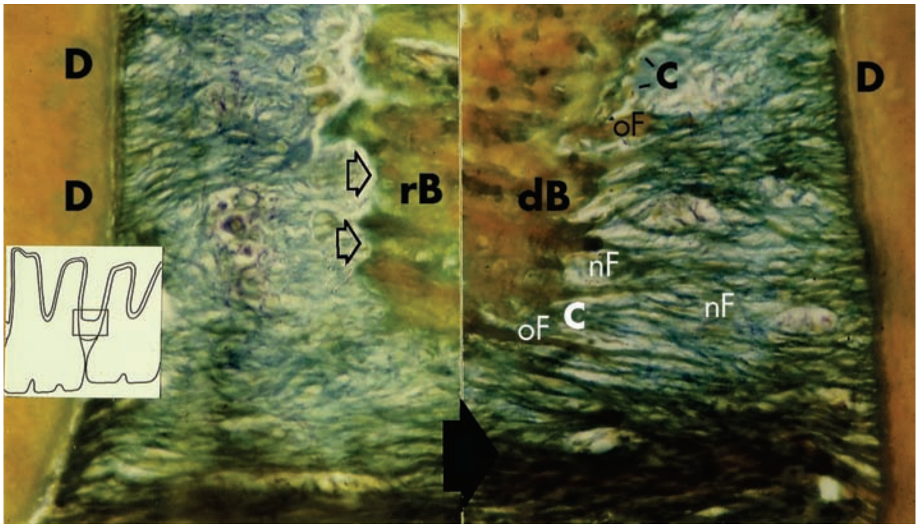

FIGURE 9-11 Physiologic migration in the rat in the interdental area in direction of *black arrow*. *rB,* Resorptive alveolar bone surface *(open arrows)*; *dB,* depository alveolar bone surface; *oF,* older fibers included in the new bone formation by osteoclasts; *nF,* new fibrils near the bone surface and in the middle of the PDL; *C,* osteoblasts; *D,* dentin.

tipping of first molars in rats[5] indicated that (1) up to a certain level of stress or duration, the reactions occur mainly in the periodontal membrane with increasing vascularization, cell proliferation, fiber formation, and osteoid application on the bone surfaces and (2) beyond a certain level of stress or duration, decreased vascular supply in the PDL and destruction of cells between stretched fibers occur. The reactions become more significant within the alveolar bone, with removal and undermining resorption of Sharpey fibers from the rear (Figure 9-13), subsequently permitting vascular invasion of cells into the periodontal membrane from the alveolar bone.

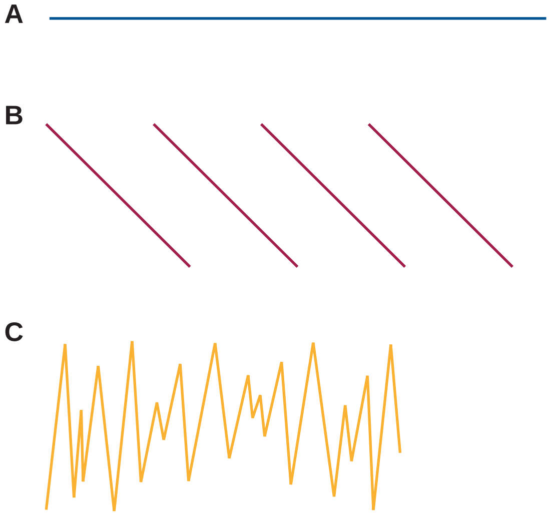

FIGURE 9-12 Orthodontic forces: **A,** continuous; **B,** interrupted continuous; **C,** intermittent.

A light force over a certain distance moves a tooth more rapidly and with fewer injuries to the supporting tissues than a heavy one. The purpose of applying a light force is to increase cellular activity without causing undue tissue compression and to prepare the tissues for further changes. Another reason for applying light forces is that it results in less discomfort and pain to the patient. Unmyelinated nerve endings persist in the hyalinized tissue, and they are more or less compressed during the initial stage.

The *duration* of force, equivalent to treatment time, is considered to be a more crucial factor than the magnitude of the force regarding adverse tissue reactions, especially in connection with long treatment periods and in cases with high density of the alveolar bone.

Direction of forces will result in different kinds of tooth movements. All tooth movements can be described

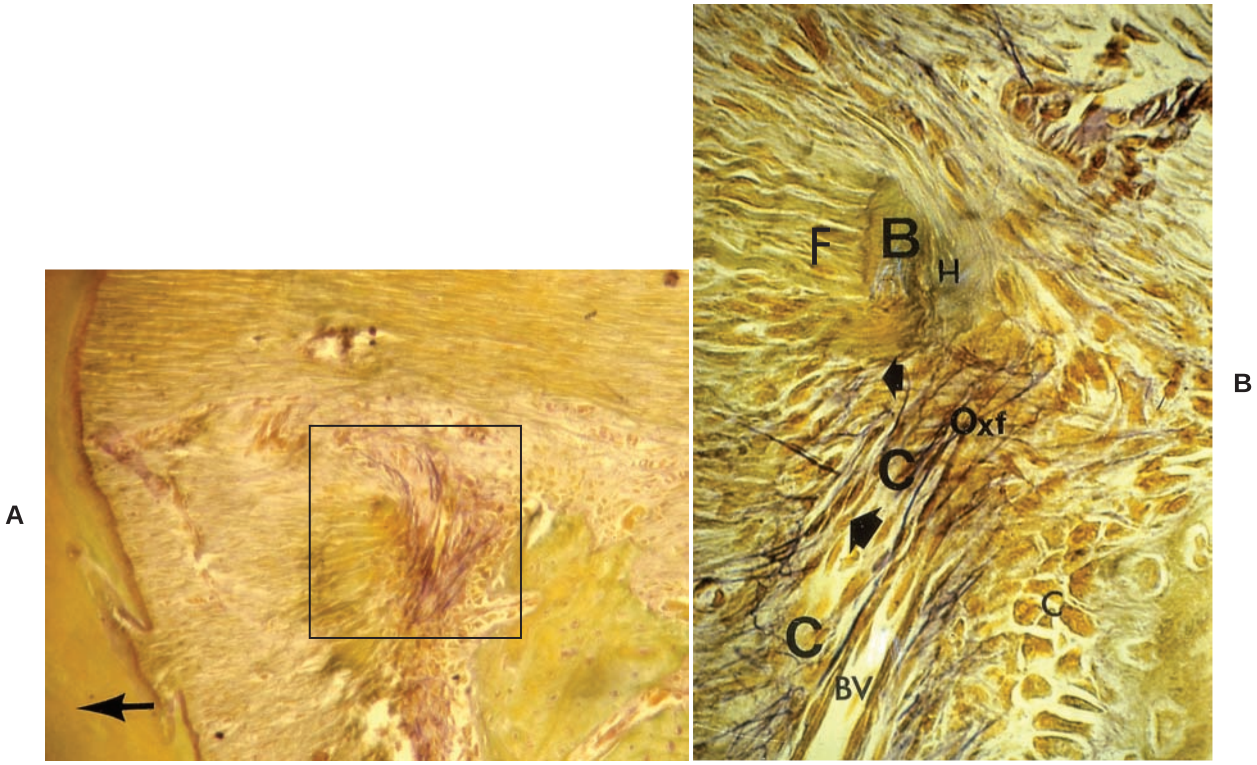

FIGURE 9-13 **A,** Area of tension of 28-day duration in the rat. Tooth moved in the direction of the arrow. Interface between Sharpey fibers *(F)* and alveolar bone *(B)* near the alveolar crest. **B,** Area corresponding to *box* in **A.** Sections are 6 μm apart. Note the proliferation of blood vessels *(BV)* in the alveolar bone, detaching periodontal membrane fibers from the bone surface from the rear. Blood vessels have infiltrated the alveolar bone plate *(B)* from the rear. Sharpey fibers and parts of the alveolar bone have disappeared. *C,* Undermining resorption; *H,* hyalinization, *Oxf,* oxytalan fibrils. *(From Rygh P, et al: Activation of the vascular system: a main mediator of periodontal fiber remodeling in orthodontic tooth movement,* Am J Orthod *89:453, 1986.)*

in terms of rotation and translation. This discussion addresses only the small, initial tooth movements that occur within the periodontal space. Clearly, the larger long-term movements are the result of a succession of such minor movements, depending on the pattern of socket remodeling. For the purposes of illustration, forces and movements are often presented in terms of *tipping, torquing, bodily, intrusion, extrusion, and rotation*. The different types of tooth movements will be discussed next.

TISSUE RESPONSE IN PERIODONTIUM

In 1905, Carl Sandstedt's studies[6] in dogs convincingly demonstrated that tooth movement is a process of resorption and apposition. He gave the first description of the glasslike appearance of the compressed tissue, termed *hyalinization,* which has been associated with a standstill of the tooth movement. It was not until the 1950s that tooth movements attracted wider attention with Kaare Reitan's classic study *The initial tissue reaction incident to orthodontic tooth movement as related to the influence of function.*[7] Reitan used the dog as his experimental model but also extracted teeth from humans. Histology was his means to address the questions of clinical importance, such as the identity of the factors that control and regulate the pattern of tooth movement in different individuals. In this way he explored age, sex, the type of alveolar bone, the kind of forces, and the matrix of cells of the gingival and periodontal ligament. He pointed out differences in the tissue response between animals and humans. Per Rygh continued Reitan's research to explain why orthodontic tooth movements might cause damage to the tooth, possibly as a sequelae of the hyalinization process.

Reitan and Rygh, dear friends and scientific colleagues, were my co-authors in "Tissue Reactions" in the third and fourth editions of *Orthodontics: Current Principles and Techniques*. They are remembered with gratitude even in this fifth edition.

Initial Period of Tooth Movement

Application of a continuous force on the crown of the tooth leads to tooth movement within the alveolus that is marked initially by narrowing of the periodontal membrane, particularly in the marginal area. After a certain period, osteoclasts differentiate along the alveolar bone wall, as occurs in young humans after 30 to 40 hours.[8] All permanent alterations depend on cellular activity. When conditions are favorable, the cells increase in number and differentiate into osteoclasts and fibroblasts. The width of the membrane is increased by osteoclastic removal of bone, and the orientation of the fibers in the periodontal membrane changes, as does the arrangement of the ground substance (Figure 9-14). Experimental studies indicate that fibroblasts not only are capable of synthesizing fibrous tissue and ground substance but also play an important role in the breakdown of connective tissue. These processes occur simultaneously.[9]

Hyalinization Phase

During the crucial stage of the *initial application of force,* compression in limited areas of the membrane frequently impedes vascular circulation and cell differentiation, causing degradation of the cells and vascular structures rather than proliferation and differentiation. The tissue reveals a glasslike appearance in light microscopy, which is termed *hyalinization* (Figure 9-15). It is caused partly by anatomic and partly by mechanical factors and is almost unavoidable in the initial period of tooth movement in clinical orthodontics. Hyalinization represents a sterile necrotic area, characterized by three main stages: degeneration, elimination of destroyed tissue, and establishment of a new tooth attachment.

Degeneration starts where the pressure is highest and the narrowing of the membrane is most pronounced, that is, around bone spicules. Degeneration may be limited to parts of the membrane or extend from the root surface to the alveolar bone. Electron microscopy[10–13] has shown that advanced cellular and vascular changes may occur within a few hours of the application of the force. Retardation of the blood flow is followed by disintegration of the vessel walls and degradation of blood elements, all occurring by mechanisms different from those seen during physiologic breakdown (Figure 9-16). The cells undergo a series of changes, starting with a swelling of the mitochondria and the endoplasmic reticulum and continuing with rupture and dissolution of the cytoplastic membrane. This leaves only isolated nuclei between compressed fibrous elements (pyknosis) and is the first indication of hyalinization.

In hyalinized zones, the cells cannot differentiate into osteoclasts and no bone resorption can take place from the periodontal membrane. Tooth movement stops until the adjacent alveolar bone has been resorbed, the hyalinized structures are removed, and the area is repopulated by cells. A limited hyalinized area occurring during the application of light forces may be expected to persist from 2 to 4 weeks in a young patient (Figure 9-17). When bone density is high, the duration is longer.

The peripheral areas of the hyalinized compressed tissue are *eliminated* by an invasion of cells and blood vessels from the adjacent undamaged PDL. The hyalinized materials are ingested by the phagocytic activity of macrophages and are removed completely[14] (Figure 9-18, *A)* The adjacent alveolar bone is removed by indirect resorption by cells that have differentiated into osteoclasts on the surfaces of adjacent marrow spaces or, if the alveolar wall and the outer cortical bone are fused, on the surface of the alveolar process (Figure 9-18, *B*).

Reestablishment of the tooth attachment in the hyalinized areas starts by synthesis of new tissue elements

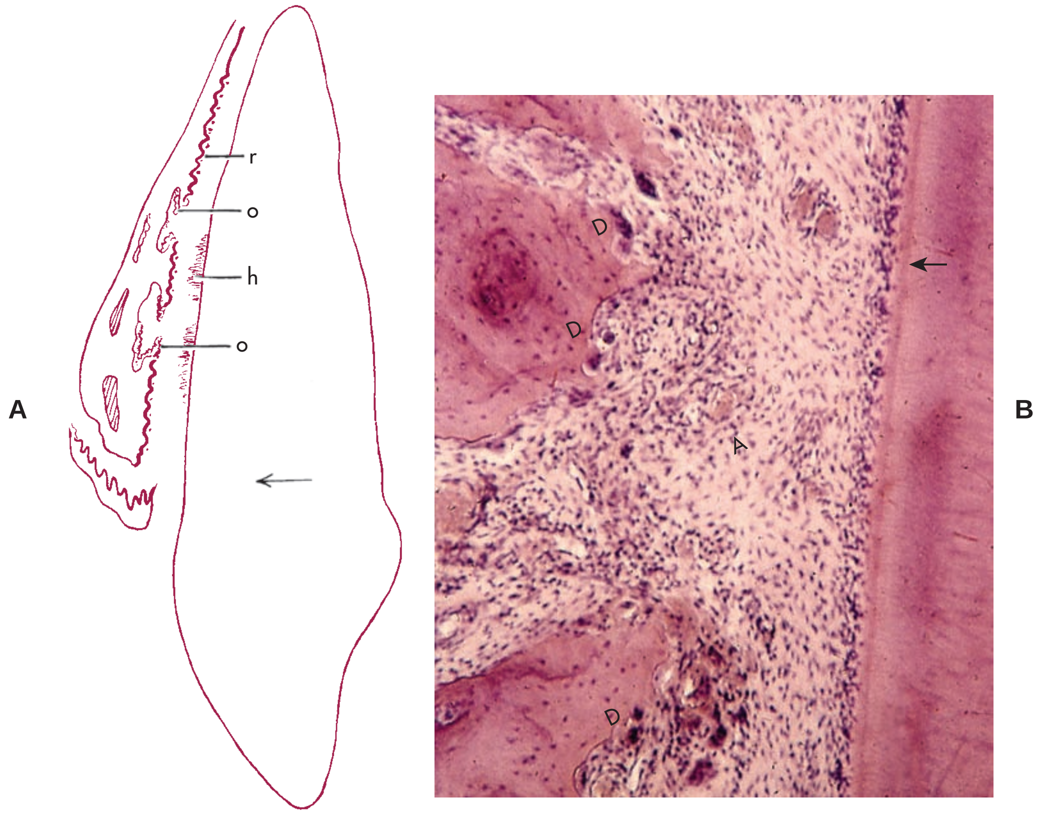

FIGURE 9-14 **A,** Location of bone resorption adjacent to the apical third of an upper canine in a 39-year-old patient. The tooth was moved continuously for 3 weeks. *o,* Compensatory formation of osteoid in open marrow spaces; *h*, remnants of hyalinized tissue adhering to the root surface; *r,* direct bone resorption adjacent to the apical third of the root. **B,** Direct bone resorption with osteoclasts along the bone surface *(D)* (area marked *r* in A). *A,* Absence of epithelial remnants in adjacent periodontal tissue, center of the formerly cell-free zone; note the widening of the periodontal space. *D,* Direct bone resorption with osteoclasts.

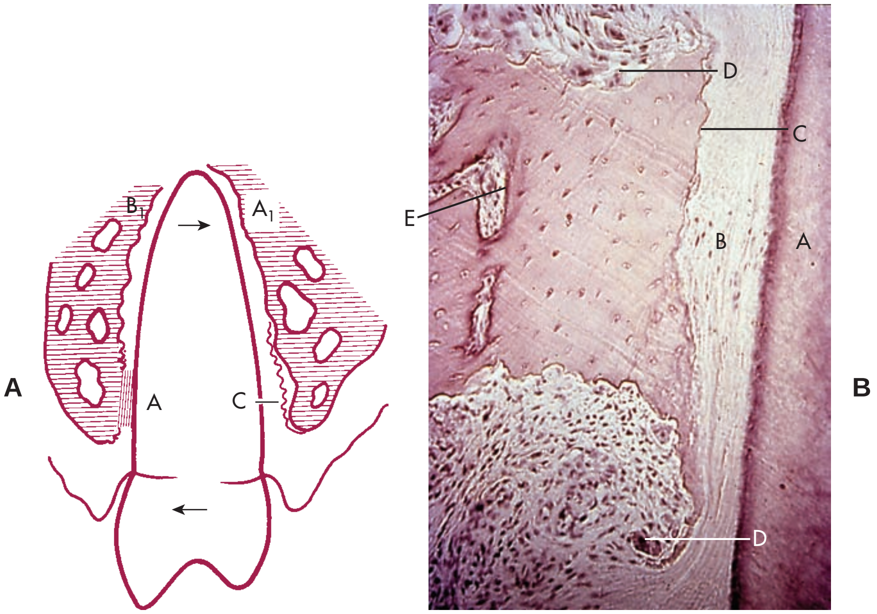

FIGURE 9-15 **A,** In most cases, tooth movement is initiated by formation of a cell-free area at *A* and new osteoid formed at *C*. A_1 and B_1 represent corresponding pressure and tension sides in the apical region. **B,** Area corresponding to *A* in **A**: the upper first premolar in a 12-year-old patient. Hyalinization of fairly long duration, here mainly caused by high bone density. No osteoclasts have been formed in the marrow spaces. *A,* Root surface; *B,* remaining pyknotic cell nuclei in hyalinized tissue; *C,* reversal line; *D,* direct bone resorption with osteoclasts; *E,* marrow space.

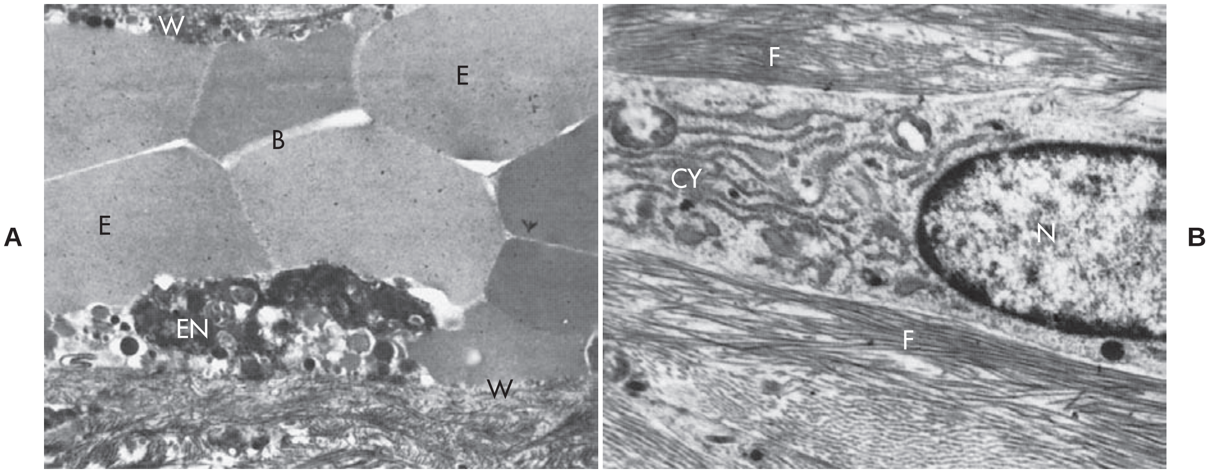

FIGURE 9-16 **A,** Early capillary changes in the hyalinized zone (human tissue) as seen with the electron microscope; findings usually not visible by light microscopy (force, 70 cN; duration, 2 days [×6000]). *E,* Stasis with packing of erythrocytes; *B,* borderline between red blood cells; *W,* disappearance of the capillary wall; *EN,* endothelial cell undergoing disintegration**. B,** Principal fibers on the tension side in the rat (force, 10 cN; duration, 28 days [×9000]). *F,* Fibrils subjected to moderate tension and located on both sides of the fibroblast; *N,* nucleus; *CY,* cytoplasm with well-developed endoplasmic reticulum. Prolonged stretching of supraalveolar fibers may cause disappearance of similarly located cellular elements as a result of compression. *(From Rygh P: Ultrastructural vascular changes in pressure zones of rat molar periodontium incident to orthodontic tooth movement,* Scand J Dent Res *80:307, 1972.)*

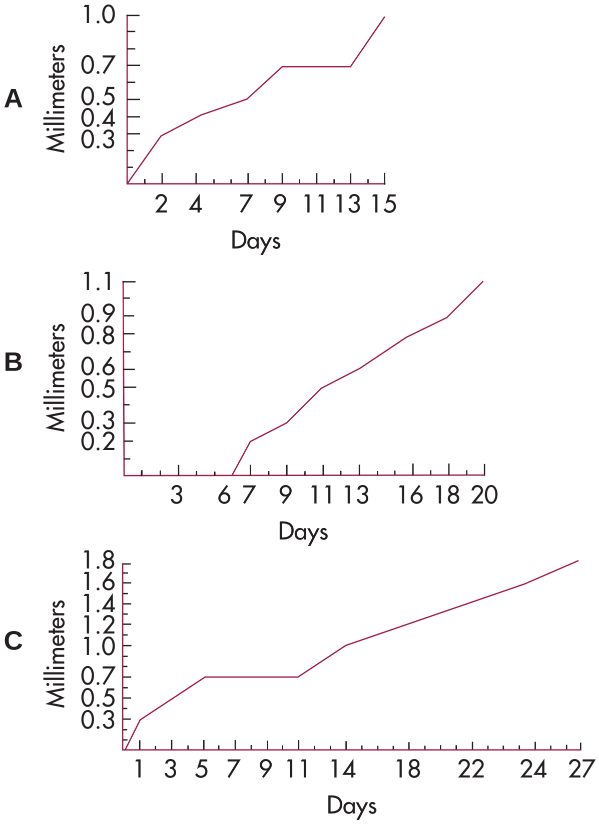

FIGURE 9-17 Movement of upper premolars with Bimler's removable appliances (force, 70 to 100 cN). Note the short hyalinization periods. **A,** A cell-free zone lasted for about 4 days. **B,** The appliance remained passive during the first 6 days. Tooth movement amounted to 1.1 mm during 14 days started after a layer of gutta-percha had been added. **C,** A cell-free area existed from the fifth to the eleventh day.

as soon as the adjacent bone and degenerated membrane tissue have been removed. The ligament space is now wider than before treatment started, and the membranous tissue under repair is rich in cells.[3]

Hyalinized Zone and Root Resorption. A side effect of the cellular activity during the removal of the necrotic hyalinized tissue is that the cementoid layer of the root and the bone are left with raw unprotected surfaces in certain areas that can readily be attacked by resorptive cells[15,16] (Figure 9-19, *A*). Root resorption then occurs around this cell-free tissue, starting at the border of the hyalinized zone (Figure 9-19, *B*).

Some of these small resorption lacunae are visible only by the scanning microscope. According to Kvam[17] organic tissue tends to remain in the resorbed area, which can be exposed more clearly by removing the organic components (Figure 9-20). These initial injuries are small and insignificant.

Light and transmission electron microscopy have shown that root resorption occurs near the hyalinized zone in close proximity to a rich vascular network.[10] This has been verified by Brudvik and Rygh,[18–19] who showed occurrence of small lacunae in the cementum at the coronal and apical peripheries of the hyalinized zone (Figure 9-21). Their results indicated an association between root resorption and active removal of the hyalinized necrotic tissue. The first sign of root resorption (*initial phase*) was defined as a penetration of cells from the periphery of the necrotic tissue where mononucleated fibroblast-like cells, stained negatively by tartrate-resistant acid phosphatase (TRAP), started removing the precementum/cementum surface. Root resorption

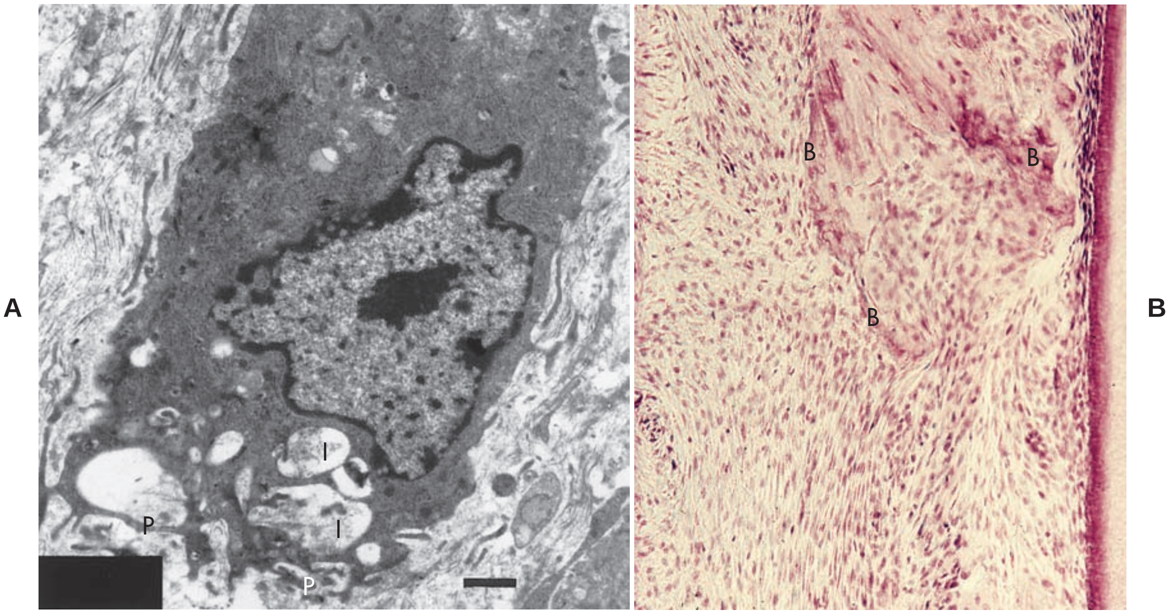

FIGURE 9-18 **A,** Pressure area in the PDL (×10,000; bar, 1 μm). Macrophage adjacent to hyalinized zone, Pseudopodia (*P*) delimit inclusions (*I*) of phagocytosed material. *(From Rygh P: Ultrastructural vascular changes in pressure zones of rat molar periodontium incident to orthodontic tooth movement,* Scand J Dent Res *80:307, 1972.)* **B,** Remaining bone areas (*B*) after the undermining resorption.

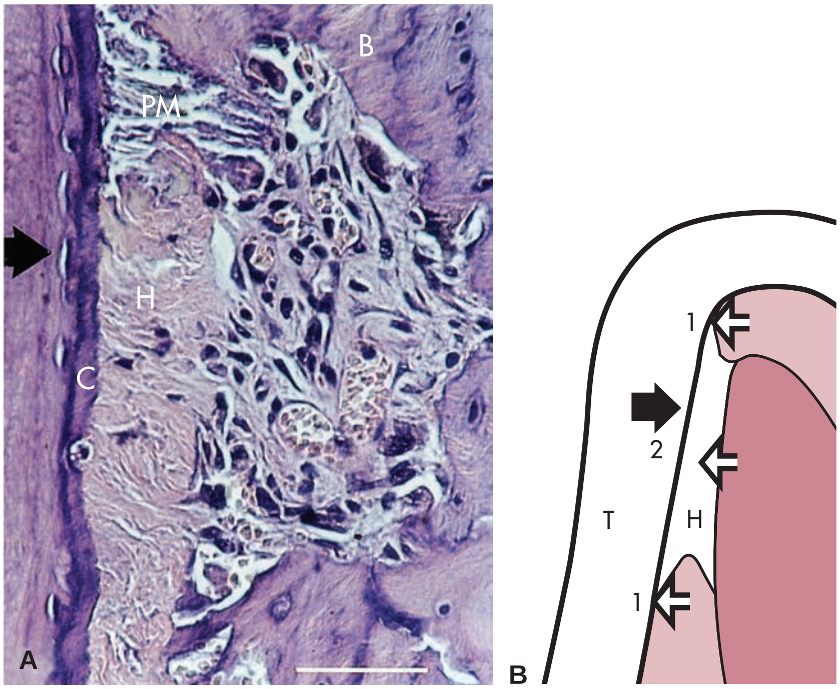

FIGURE 9-19 **A,** Migrating multinucleated cells in the middle of rat PDL close to remnants of hyalinized tissue *(H)*. *B,* Bone; *PM,* periodontal membrane close to root cementum *(C)*. **B,** Root resorption *(open arrows)* occurs first in the circumference of the hyalinized zone (*1*) and later in the central parts (*2*). *T,* Tooth; *H,* hyalinized zone; *filled arrow,* direction of tooth movement. *(From Brudvik P, Rygh P: The initial phase of orthodontic root resorption incident to local compression of the PDL,* Eur J Orthod *15:249, 1993.)*

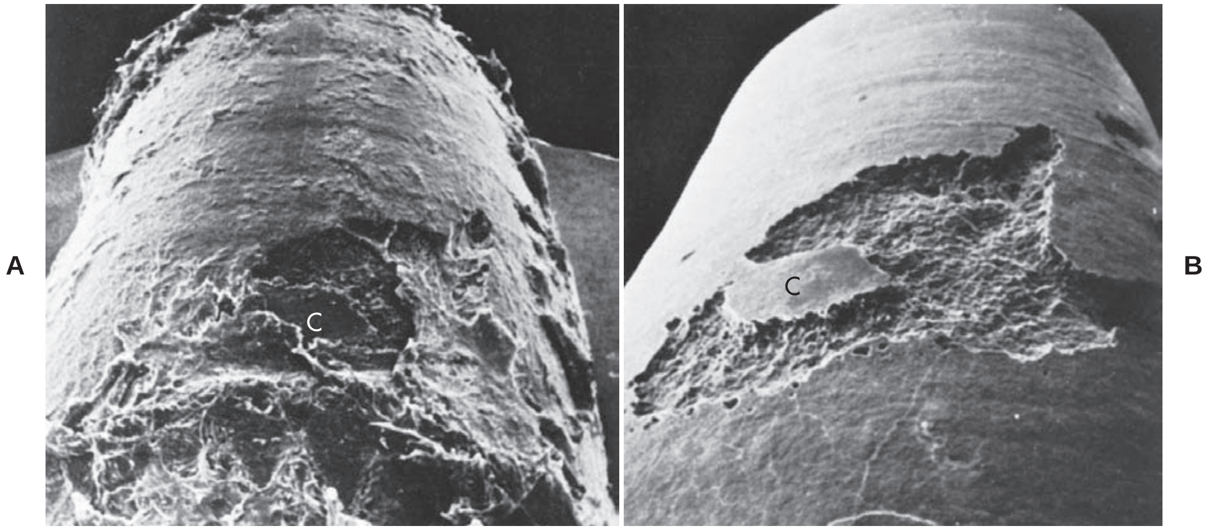

FIGURE 9-20 **A,** Resorbed lacunae in the middle third of a root as seen with the scanning electron microscope. *C,* Denuded root surface. Organic tissue components cover the major portion of the lacuna. **B,** Same root surface, previously covered by hyalinized tissue, after removal of organic tissue. *(Courtesy E. Kvam.)*

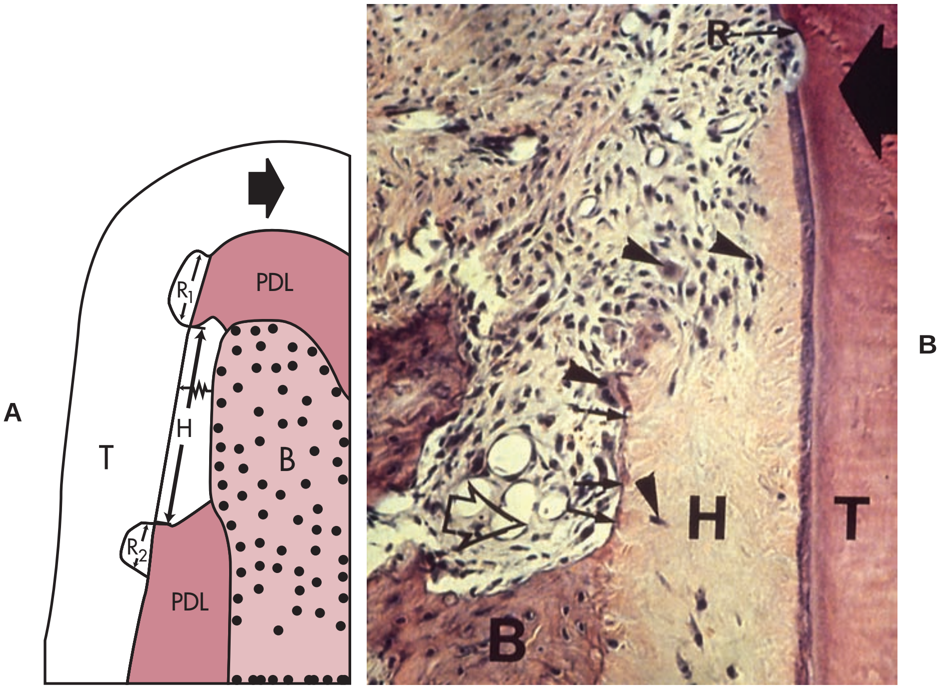

FIGURE 9-21 **A,** Schematic illustration and **(B)** photomicrograph of the hyalinized zone (*H*) between alveolar bone (*B*) and root surface *(T)*. Resorption lacunae (R$_1$ and R$_2$) after tooth movement *(large arrows)* for 7 days in the mouse. Alveolar bone resorption *(open arrows)* occurs from marrow spaces; *small arrows* indicate thin line of bone between the resorbed bone and hyalinized tissue (bar is 50 μm). Resorption lacunae *(R)* with TRAP-negative cells; TRAP-positive cells (*arrowheads*) at the margin of and in the main hyalinized tissue. *(Adapted from Brudvik P, Rygh P: The initial phase of orthodontic root resorption incident to local compression of the PDL,* Eur J Orthod *15:249, 1993; Brudvik P, Rygh P: Root resorption beneath the main hyalinized zone,* Eur J Orthod *16:249, 1994.)*

beneath the main hyalinized zone occurred in a *later phase* during which multinucleated TRAP-positive cells were involved in removing the main mass of necrotic PDL tissue and resorbing the outer layer of the root cementum. Further studies indicated that after the multinucleated TRAP-positive cells reached the subjacent contaminated and damaged root surface and removed the necrotic periodontal tissue, they continued to remove the cementum surface.

When the movement is discontinued, *repair* of the resorbed lacunae occurs, starting from the periphery (Figure 9-22). After the force has terminated, active root

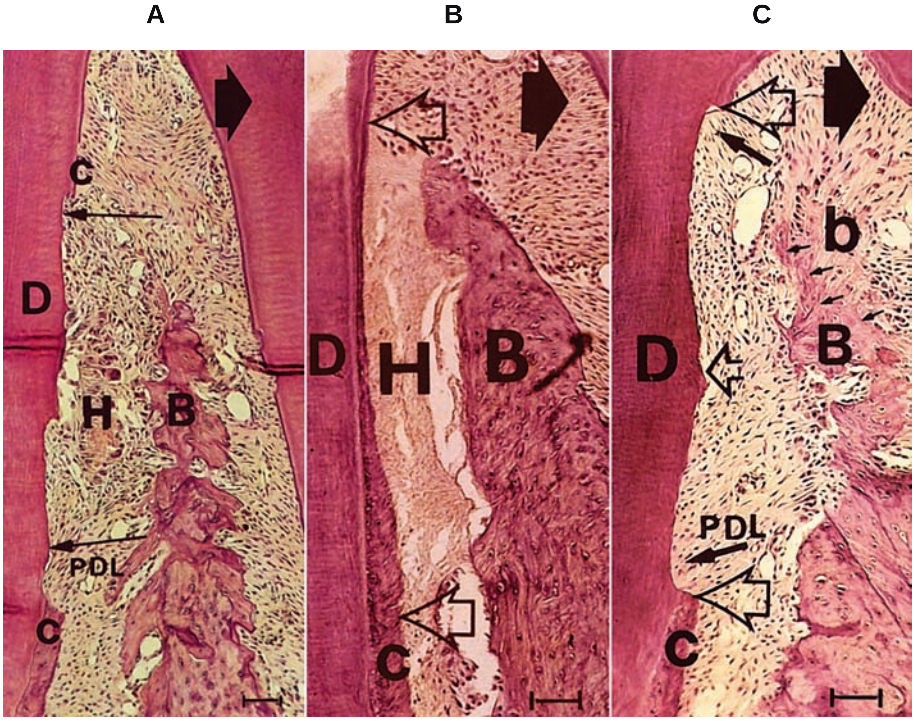

FIGURE 9-22 Photomicrographs of the root resorption and repair sequence of the compressed PDL 21 days after tooth movement in the direction of large arrows. **A,** Neighboring section with repair of peripheral parts of resorption lacunae by deposition of cementum *(arrows)*. **B,** The length (between two *open arrows*) of the hyalinized zone after 3 days of compression. **C,** The length (between two *large open arrows*) of the resorbed root surface after 21 days of tooth movement. Note the regular arrangement of the PDL cells and fibers in the peripheral part of the resorption lacunae *(medium arrows)*. In the central part of resorption area (*medium open arrows*) no trace of fibers is connected with the root surface. Demarcation line *(small arrows)* between old bone (*B*) and new bone *(b)* in crest area. *C,* Cementum, *D,* dentin; *H,* hyalinized zone. *(Adapted from Brudvik P, Rygh P: Transition and determinants of orthodontic root resorption-repair sequence,* Eur J Orthod *17:177, 1995.)*

resorption by TRAP-positive cells in the resorption lacunae still was observed in areas where hyalinized tissue existed[20–21] (Figure 9-23). After the hyalinized tissue was eliminated, fibroblast-like cells invaded the active resorption site. After termination of force and in the absence of hyalinized necrotic tissue in the PDL, repair on the resorption lacunae occurred. The first sign was synthesis of collagenous fibrillar material by fibroblast- and cementoblast-like cells, followed by reestablishment of the new PDL. Further studies are needed, however, to fully clarify the factors leading to transition of an active process of resorption into one of repair.

A reduction of root resorption is likely provided by minor trauma and can be repaired during periods of no force or possibly during periods of extremely low force application (Figure 9-24).

Secondary Period of Tooth Movement

In this period (Figure 9-25), the PDL is considerably widened. The osteoclasts attack the bone surface over a much wider area. As long as the force is kept within certain limits or gentle reactivation of the force is undertaken, further *bone resorption* is predominantly direct (Figure 9-26). The fibrous attachment apparatus is reorganized by the production of new periodontal fibrils. When the application of a force is favorable, a large number of osteoclasts appear along the bone surface on the pressure side and tooth movement is rapid. Modern histologic techniques reveal that complete reorganization of the fibrous system takes place throughout the membrane.

The main feature is the *deposition of new bone* on the alveolar surface from which the tooth is moving away (tension side). Cell proliferation usually occurs after 30 to 40 hours in young human beings. The newly formed cells, osteoblasts with darkly stained nuclei, have a characteristic appearance (Figure 9-27). Osteoblasts may be observed along stretched fiber bundles. Shortly after cell proliferation has started, osteoid tissue is deposited on the tension side. The formation of this new osteoid depends to some extent on the form and thickness of the fiber bundles. The original periodontal fibers become embedded in the new layers of pre-bone, or osteoid, which mineralizes in the deeper parts.[3]

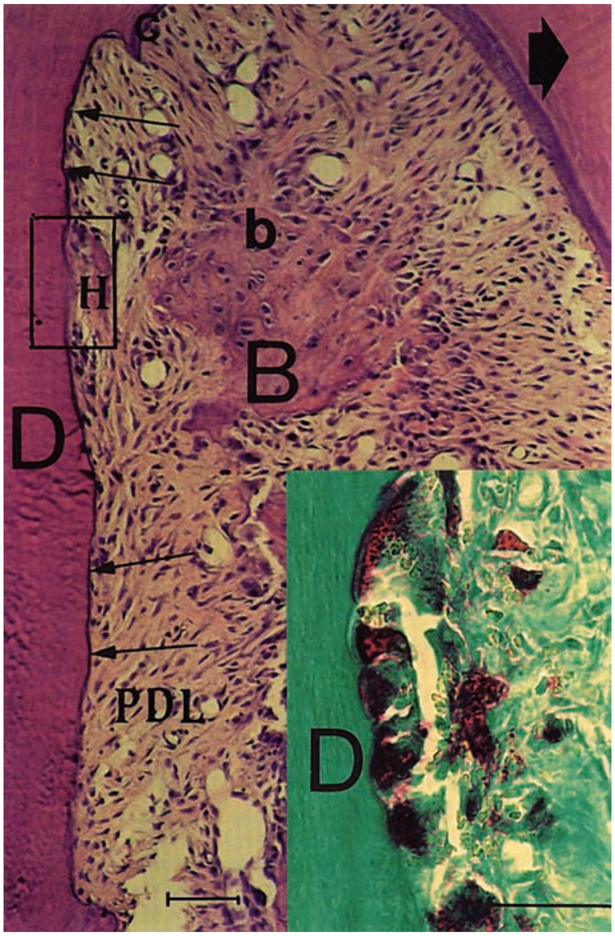

FIGURE 9-23 Repair of lacuna by cementum deposition in the periphery *(arrows).* Small amounts of hyalinized tissue (*H)* persist in boxed area, which shows active root resorption indicated by TRAP-positive cells in the lacuna (*bars* are 50 μm). The heavy arrow (upper right) indicates direction of force. *(Adapted from Brudvik P, Rygh P: Transition and determinants of orthodontic root resorption-repair sequence,* Eur J Orthod *17:177, 1995.)*

New bone is deposited until the width of the membrane has returned to normal limits, and simultaneously the fibrous system is remodeled. The original stretched fibers are not broken down to the same extent as is the case on the pressure side, and the remodeling involves resorption and replacement of collagen, leading to a lengthening of the fibers, the mechanism of which is largely unknown.

Concomitantly with bone apposition on the periodontal surface on the tension side, an accompanying resorption process occurs on the spongiosa surface of the alveolar bone that tends to maintain the dimension of the supporting bone tissue (Figure 9-28). Correspondingly, during the resorption of the alveolar bone on the pressure side, maintenance of the alveolar lamina thickness is ensured by apposition on the spongiosa surface. These processes are mediated by the cells of the endosteum, which cover all the internal bone surfaces and dental alveoli. Extensive remodeling takes place in the deeper cell-rich layers of the periosteum, incident to the orthodontic forces, a reaction that tends to restore the thickness of the supporting bone.

The observation that orthodontic tooth movement involves many *inflammation-like* reactions is important in that this, in turn, has enhanced an understanding that the whole cascade of factors involved in inflammation may be part of the reactions to orthodontic forces in the tooth-supporting tissues: that is, extracellular breakdown of collagen by collagenases, produced by leukocyte–fibroblast interaction. The term *inflammation* should not be confused with the term *infection*, as is often the case in popular use. In orthodontics, inflammation is a process occurring in a local environment when a rapid response is needed for a stress that is felt transiently by the cells as being too heavy.

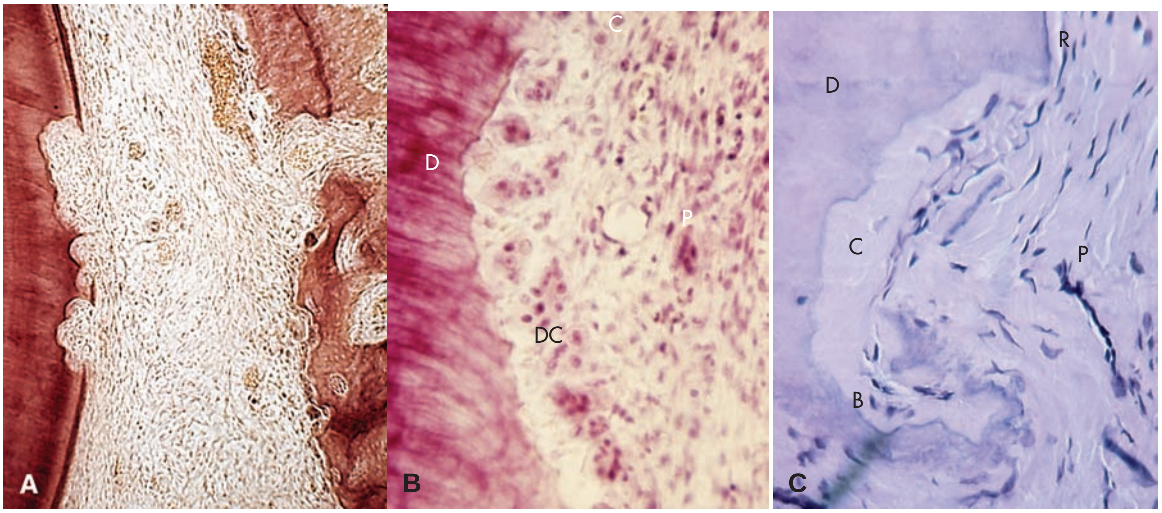

FIGURE 9-24 **A,** Superficial root resorption. **B,** Magnification of the resorption area in **A.** *D,* Dentin; *DC,* dentinoclasts. **C,** Repaired lacuna. *B,* Demarcation; *C,* secondary cementum; *D,* dentin; *P,* periodontal ligament.

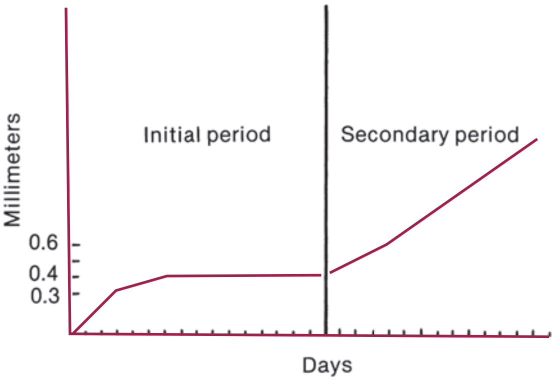

FIGURE 9-25 Degree of tooth movement before and after hyalinization. Tooth movement occurring after hyalinization is termed *secondary period.*

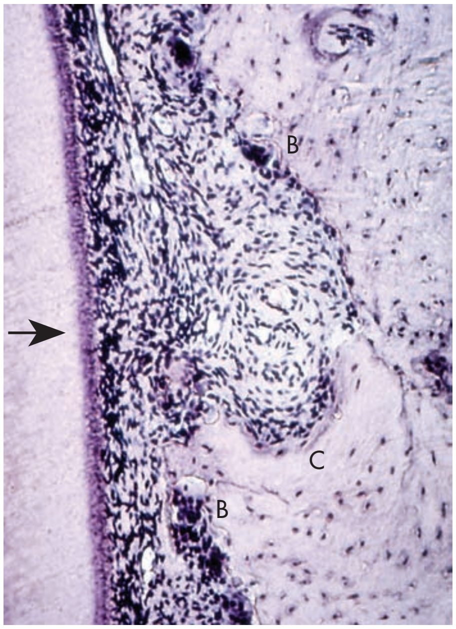

FIGURE 9-26 Effect on the pressure side of the upper premolar of a 12-year-old who wore a gradually expanded loose activator every night for 2 weeks. The root was moved as indicated by the *arrow*. The alveolar bone was bordered by an osteoid layer that persists. Extensive bone resorption has occurred in the area subjacent to this osteoid tissue. *B,* Bone surface lined with osteoclasts; *C,* persisting layer of osteoid. Note the increase in cellular elements.

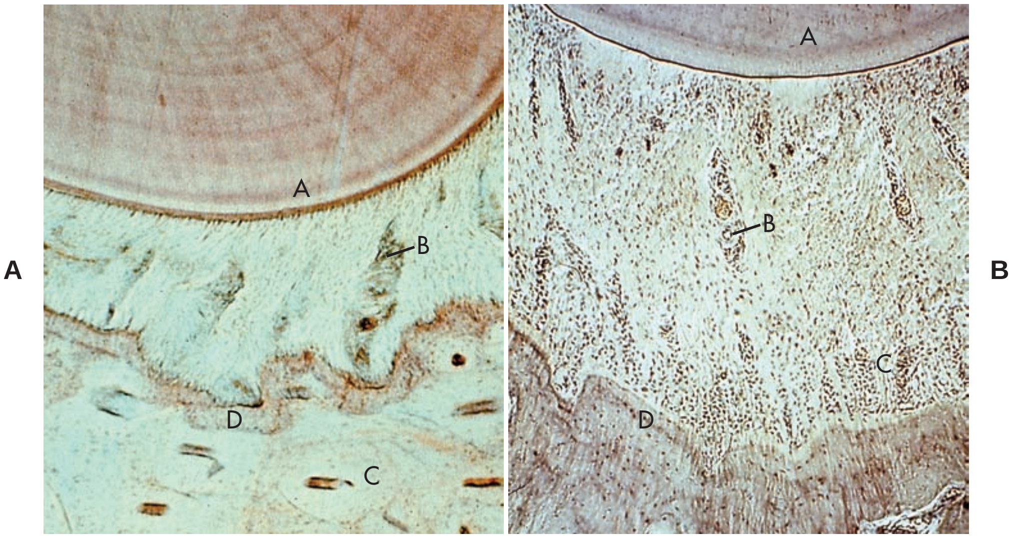

FIGURE 9-27 Animal experiment on initial movement of short duration in the upper central and lateral incisors. **A,** Control. *A,* Tooth root; *B,* interstitial space; *C,* bundle bone; *D,* undecalcified osteoid layer. **B,** Experimental second inscisor, tension side (force, 45 cN; duration, 36 hours). Note the increase and spreading of new cells, particularly in areas close to the bone surface and adjacent to the stretched fiber bundles. *A,* Tooth root; *B,* interstitial space; *C,* proliferating osteoblasts between fiber bundles; *D,* increase in osteoid tissue.

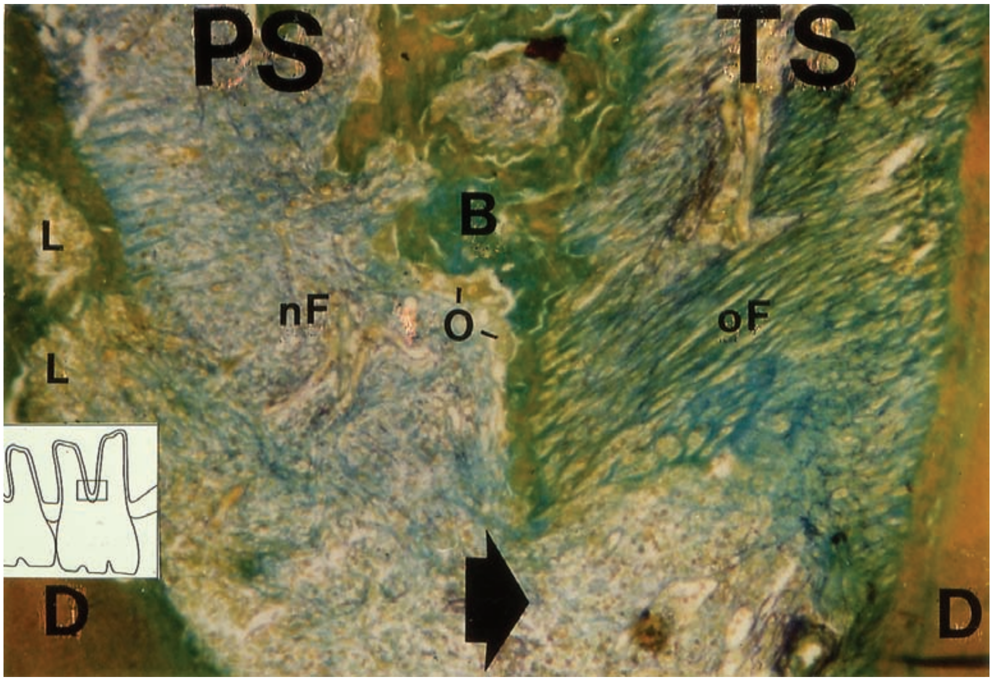

FIGURE 9-28 Experimental tooth movement *(arrow)* in the rat in the interradicular bone *(B)* and dentin *(D)*. On the pressure side *(PS)*, the bone is being actively resorbed by osteoclasts. Original fibers *(oF)* on the tension side *(TS)* are stretched and embedded in bone deposited on the alveolar surface. Note the complete breakdown of the original fibers and their replacement of new fibrils *(nF)* in the richly vascularized pressure side. *L,* Root resorption lacunae.

Types of Tooth Movements

The tissue response in different parts of the PDL is dependent on the type of tooth movement, which briefly will be exemplified.

Tipping. Tipping of a tooth leads to a concentration of pressure in limited areas of the PDL (Figure 9-29, *A*). A fulcrum is formed, which enhances root movement in the opposite direction. A tipping movement in general results in the formation of a hyalinized zone slightly below the alveolar crest, particularly when the tooth has a short, undeveloped root. If the root is fully developed, the hyalinized zone is located a short distance from the alveolar crest (Figure 9-29, *B*). Tipping of a tooth by light continuous forces results in a greater movement within a shorter time than that obtained by any other method. In most young orthodontic patients, bone resorption resulting from a moderate tipping movement usually is followed by compensatory bone formation. The degree of such compensation varies individually and depends primarily on the presence of bone-forming osteoblasts in the periosteum. Compensatory periosteal bone apposition in the apical region is also subject to some variation, according to whether osteoblasts are present or absent in the periosteum (Figure 9-30).

Torque. A torquing movement of a tooth involves tipping of the apex (Figure 9-31, *A*). During the initial movement of torque the pressure area usually is located close to the middle region of the root. This occurs because the PDL is normally wider in the apical third than in the middle third. After resorption of bone areas corresponding to the middle third, the apical surface of the root gradually begins to compress adjacent periodontal fibers and a wider pressure area is established (Figure 9-31, *B*). However, if more torque is incorporated in the archwire the force will increase and may result in resorption and fenestration of the buccal bone plate (Figure 9-32).

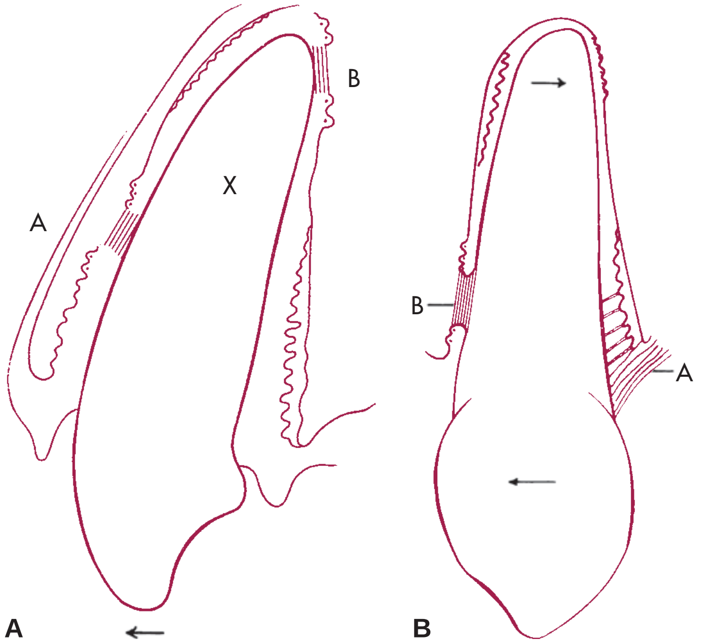

FIGURE 9-29 **A,** Location of the limited number of fiber bundles to resist movement during tipping. If the force is light, the hyalinization period will be short and the coronal portion will move quite readily. *A,* Supra-alveolar fibers; *B,* hyalinized zone on the pressure side. **B,** A prolonged tipping movement may result in formation of a secondary hyalinized zone *(A)* after the first hyalinized zone has been eliminated. Compression of the PDL is maintained in the apical region (*B*). *X,* Fulcrum.

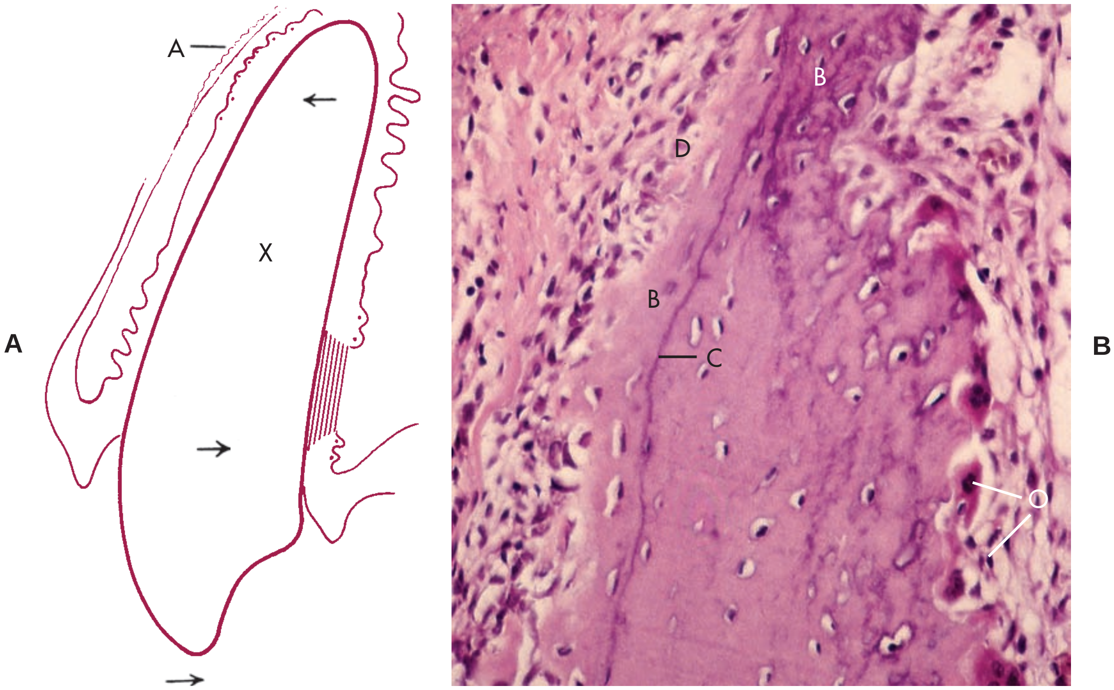

FIGURE 9-30 **A,** Compensatory bone formation on the periosteal side after tipping of an upper second incisor in the dog. *X,* Fulcrum. **B** corresponds to area *A*. *B,* Bone formation in formerly resorbed lacunae; *C,* resting line indicating thickness of the compensatory bone layer; *D,* osteoblast chain of the periosteum covering new partly calcified bone layer; *O,* osteoclasts on the bone surface.

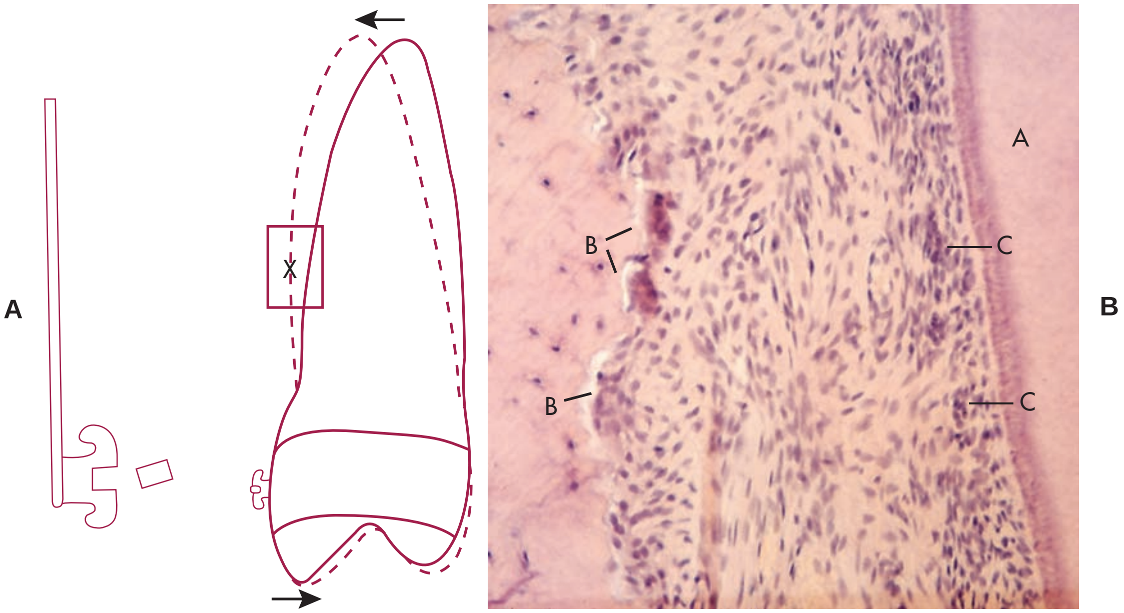

FIGURE 9-31 **A,** Torquing of an upper premolar. **B,** Pressure side in a 12-year-old patient after torquing movement performed in the apical region with a 0.021- × 0.025-inch edgewise arch (area *X* in **A**) (force, 120 to 130 cN; duration, 2 weeks). As indicated by the presence of epithelial remnants, no hyalinization of the PDL has occurred. *A,* Root surface; *B,* osteoclasts along the bone surface; *C,* epithelial remnants.

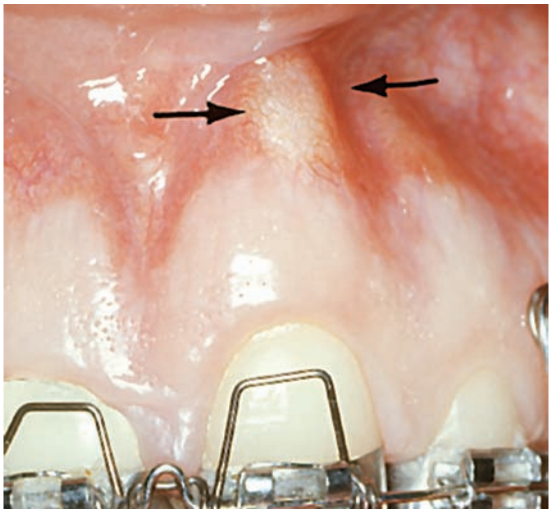

FIGURE 9-32 Bone fenestration at the left central and lateral incisors *(arrows)* after torque movements.

Bodily Movement. Bodily tooth movement is obtained by establishing a couple of forces acting along parallel lines and distributing the force over the whole alveolar bone surface. This is a favorable method of displacement provided the magnitude of force does not exceed a certain limit.[22]

Application of a light, continuous force on premolars in a dog resulted in small compressed areas shortly after the movement began, with a hyalinized zone of short duration usually located as seen in Figure 9-33, *A*. No bodily movement of the tooth in a mechanical sense is observed during this period; instead a slight tipping is noticed. The degree of initial tipping varies according to the size of the arch and width of the brackets.

The short duration of the hyalinization results from an increased bone resorption on both sides of the hyalinized tissue, especially in the apical region of the pressure side. This leads to rapid elimination of the hyalinized zone. This favorable reaction on the pressure side is caused partly by gradually increased stretching of fiber bundles on the tension side, which tends to prevent the tooth from further tipping (Figure 9-33, *B*). New bone layers are formed on the tension side along these fiber bundles (Figure 9-33, *C*).

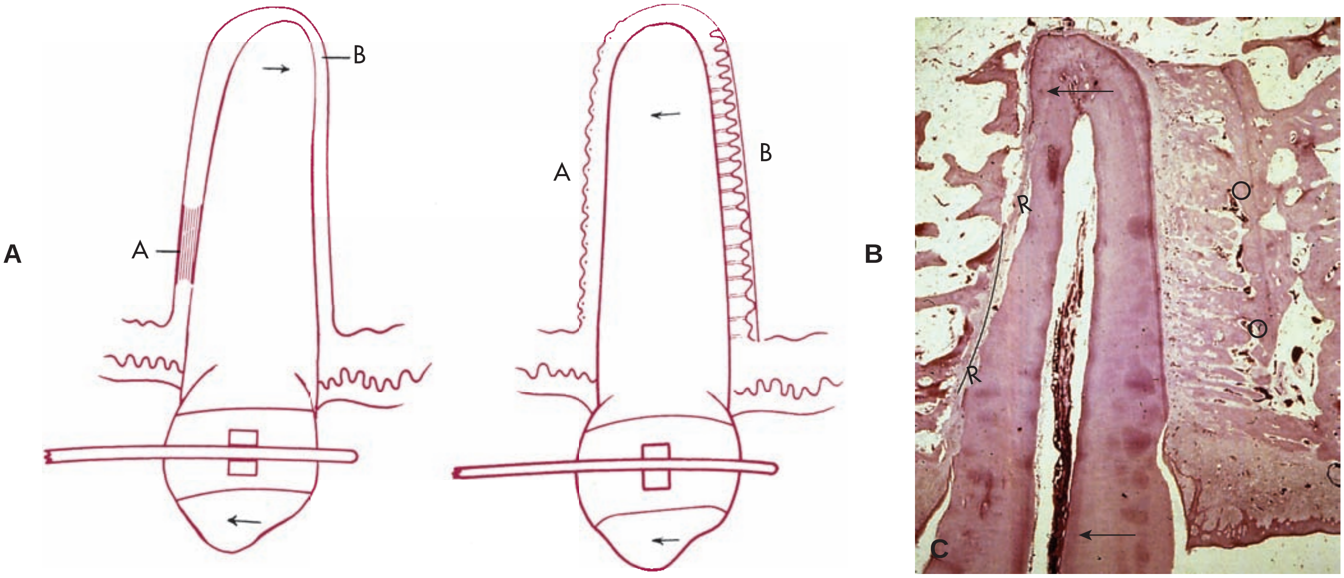

FIGURE 9-33 Two stages of bodily tooth movement. **A,** Effect observed during the initial stage of a continuous bodily tooth movement. *A,* Hyalinized tissue; *B,* slight initial compression as a result of tipping of the tooth. **B,** Undermining bone resorption terminated. Gradual upright positioning of the tooth caused increased bone resorption adjacent to the middle and apical thirds of the root. Further movement is largely controlled by stretched fiber bundles. *A,* Bone resorption on the pressure side; *B,* bone deposition along the stretched fiber bundles. The arrows denote direction of tooth movements. **C,** Bodily movement *(arrow)* of a premolar in a dog during a period of 6 months. New bone layers on the tension side with osteoblasts *(O)*. Root resorption on the pressure side *(R)*.

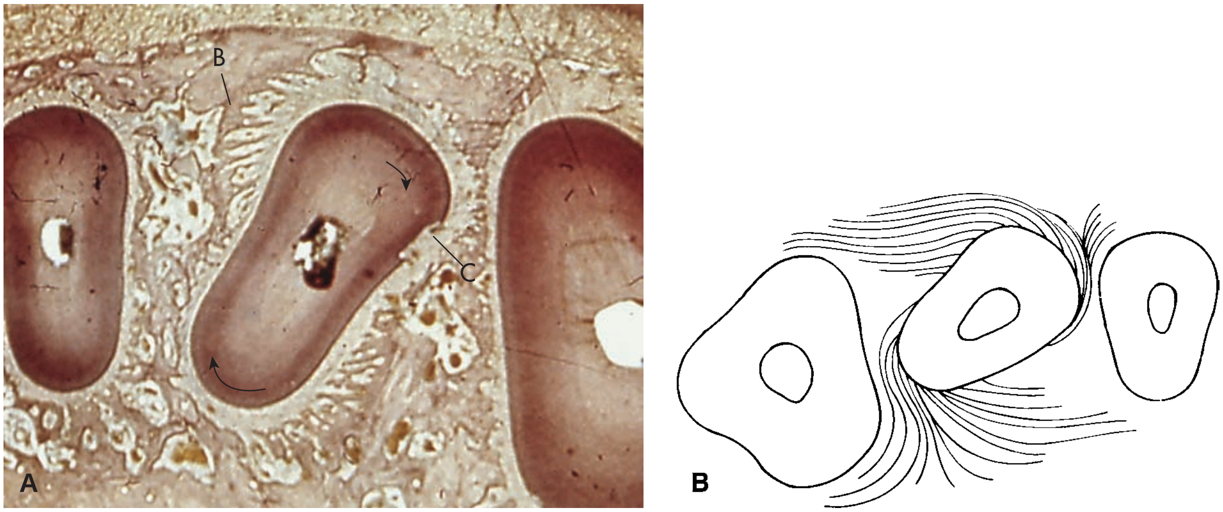

FIGURE 9-34 **A,** Experimental rotation of an upper second incisor in a dog. Formation of two pressure sides and two tension sides. *B,* Demarcation line between old and new bone layers; *C,* pressure side with root resorption. **B,** Arrangement of free gingival fibers after rotation.

Rotation. Rotation of a tooth creates two pressure sides and two tension sides (Figure 9-34, *A*) and may cause certain variations in the type of tissue response observed on the pressure sides. Hyalinization and undermining bone resorption take place in one pressure zone, while direct bone resorption occurs in the other. These variations are caused chiefly by the anatomy of the tooth and the magnitude of the force. As in other types of tooth movement, applying a light force during the initial period is favorable. On the tension side, new bone spicules are formed along stretched fiber bundles arranged more or less obliquely. In the marginal region, rotation usually causes considerable displacement of fibrous structures. The free gingival fiber groups are arranged obliquely from the root surface. Because these fiber bundles interlace with the periosteal structures and the whole supra-alveolar fibrous system, rotation also causes displacement of the fibrous tissue located some distance from the rotated tooth (Figure 9-34, *B*).

Extrusion. Extrusive movements ideally produce no areas of compression within the PDL, only tension. Even if compressed areas could be avoided, heavy forces risk "extraction" of the tooth. Light forces, however, move the alveolar bone with the tooth.

Varying with the individual tissue reaction, the periodontal fiber bundles elongate and new bone is deposited in areas of alveolar crest as a result of the tension exerted by these stretched fiber bundles (Figure 9-35, *A*). In young individuals, extrusion of a tooth involves a more prolonged stretch and displacement of the supra-alveolar fiber bundles than of the principal fibers of the middle and apical thirds. Some of the fibers may be subjected to stretch for a certain time during the tooth movement, but they will be rearranged after a fairly short retention period. Only the supra-alveolar fiber bundles remain stretched for a longer time.

Intrusion. Unlike extruded teeth, intruded teeth in young patients undergo only minor positional changes after treatment. Relapse usually does not occur, partly because the free gingival fiber bundles become slightly relaxed (Figure 9-35, *B*). Stretch is exerted primarily on the principal fibers. An intruding movement may therefore cause formation of new bone spicules in the marginal region. These new bone layers occasionally become slightly curved as a result of the tension exerted by stretched fiber bundles. Such tension also occurs in the middle third of the roots. Rearrangement of the principal fibers occurs after a retention period of a few months.

Intrusion requires careful control of force magnitude. Light force is required because the force is concentrated in a small area at the tooth apex. A light continuous force, such as that obtained in the light wire technique, has proved favorable for intrusion in young patients. In other cases the alveolar bone may be closer to the apex, increasing the risk for apical root resorption (Figure 9-36). If the bone of the apical region is fairly compact, as it is in some adults, a light interrupted force may be preferable to provide time for cell proliferation to start, and direct bone resorption may prevail when the arch is reactivated after the rest period. Intrusion may also cause changes in the pulp tissue such as vascularization of the odontoblast and pulpal edema.[23,24]

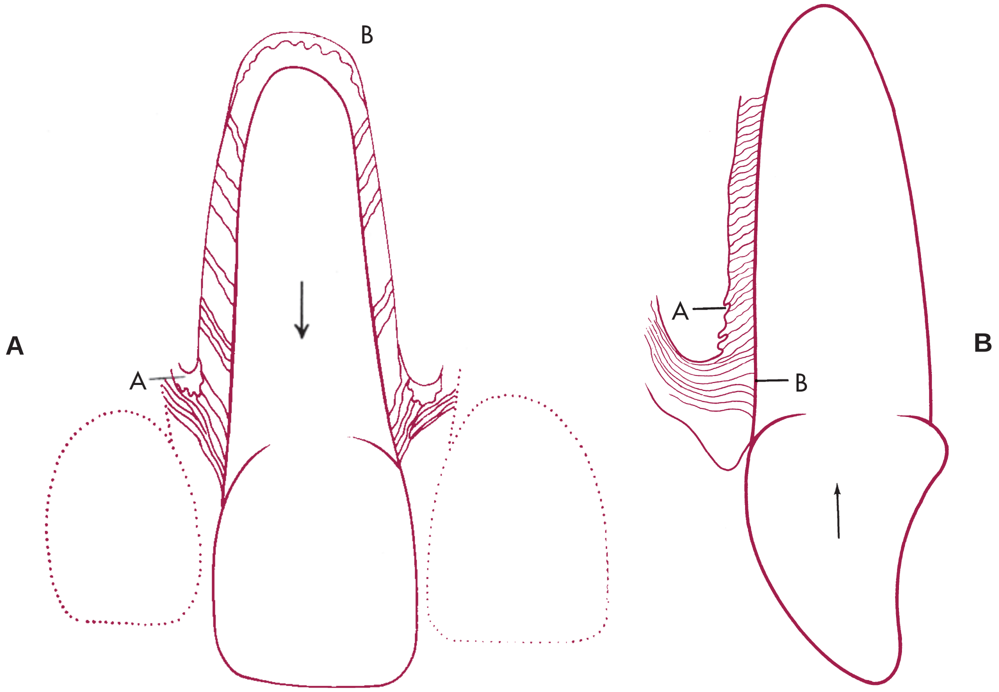

FIGURE 9-35 A, Arrangement of fiber bundles during or after *extrusion* of an upper central incisor *(arrow)*. *B,* New bone layers at the alveolar fundus. **B,** Relaxation of the free gingival fibers during *intrusion (arrow)*. *A*, Bone spicules laid down according to the direction of the fiber tension; *B,* relaxed supra-alveolar tissue.

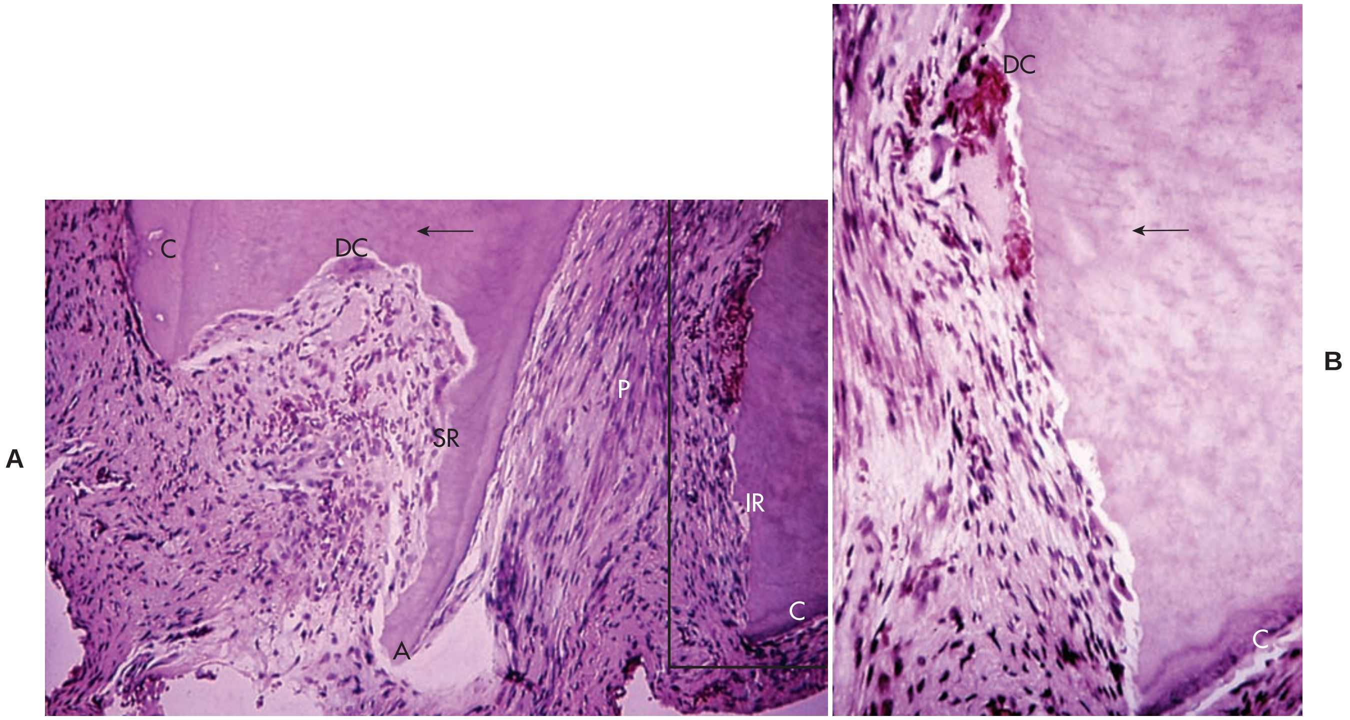

FIGURE 9-36 Apical portion of a lower first premolar tipped and intruded by a force of 100 cN for 35 days. **A,** *C,* Well-calcified cementum; *SR,* apical side resorption; *DC,* dentinoclast; *A,* remaining area of the apex, a detail of importance during reconstruction; *IR,* internal apical resorption; *P,* pulp tissue. **B,** Boxed area in **A.** *Arrows* indicate direction of applied force.

Movements in Labial/Buccal Direction

Heavy forces in labial and buccal direction may result in alveolar bone dehiscence. Experiments in monkeys and beagle dogs have shown that "predisposing" alveolar bone dehiscences may be induced by uncontrolled labial expansion of teeth through the cortical plate, thereby rendering the teeth liable to development of soft tissue recession[25–28] (Figure 9-37). Of interest to note from those studies is that labial bone reforms in the area of dehiscence with intact epithelial junction (JE) when the tooth is retracted toward a proper positioning of the root within the alveolar process[27,28] (Figure 9-38).

An experimental study in monkeys[29] in which teeth were moved orthodontically in a labial direction into areas with varying thickness and quality of the marginal soft tissue showed that a thin gingiva may serve as a locus minoris resistentiae to developing soft tissue defects in the presence of plaque-induced inflammation or toothbrushing trauma (Figure 9-39).

The *clinical implication* of the results from the studies discussed is that careful examination of the dimensions of the tissues covering the facial aspect of the teeth to be moved should precede labial tooth movement. As long as the tooth can be moved within the envelope of the alveolar process, the risk of harmful side effects in the marginal tissue is minimal, regardless of the dimensions and quality of the soft tissue.

Movements into Reduced Alveolar Bone Height

In patients with *partially edentulous dentitions* because of congenital absence or extraction of teeth, orthodontic treatment often is necessary. By positioning the teeth toward or into the edentulous area, improved aesthetics and functional results may be gained. Many of these individuals experience a *reduced alveolar bone* height.

Do tissue changes on the pressure side allow the tooth to move into such an area? An experimental study in the beagle[30] (Figure 9-40) has shown that a tooth with normal periodontal support can be moved orthodontically into an area of reduced bone height with maintained height of the supporting apparatus. On the pressure side, supporting alveolar bone was also present, extending far coronal to the surrounding, experimentally created bone level (Figure 9-41). The histologic picture of the bone tissue in the coronal portion of the root showed a large number of cells in contrast to the compact appearance of the more apically located bone, as in the unmoved tooth.

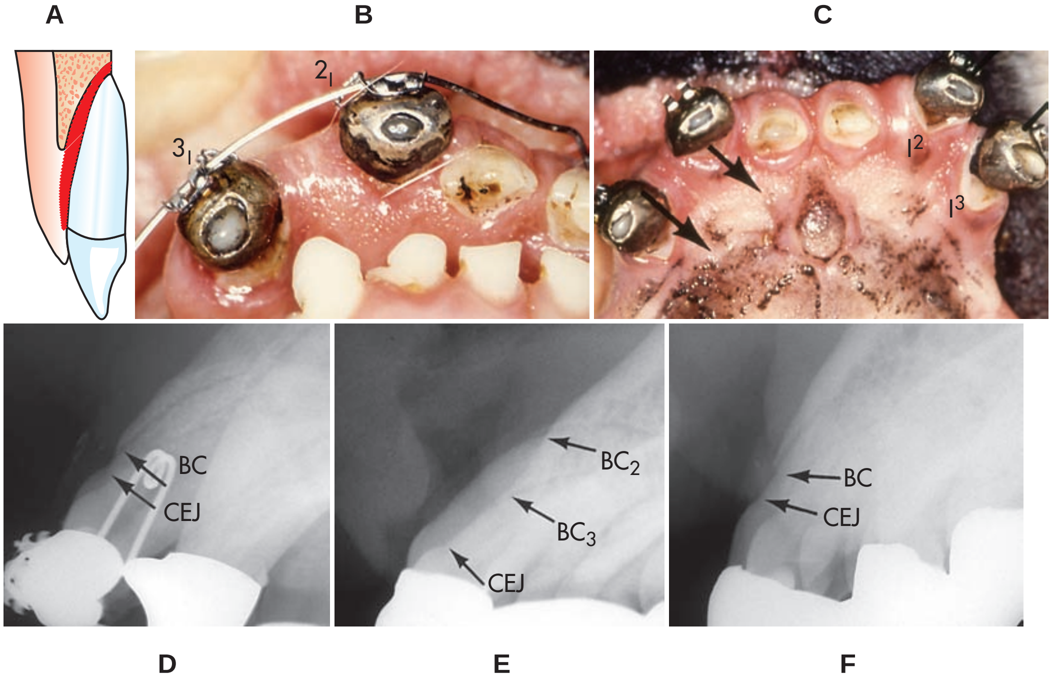

FIGURE 9-37 Bone dehiscences related to orthodontic tooth movement in a dog. **B,** The incisors *2_l* and *3_l* have been displaced through the alveolar bone plate to the level shown in **A**. **C,** The incisors *I^2* and *I^3* have been moved back to their original position; simultaneously *I^2* and *I^3* are displaced labially (days 150 to 300). Radiographs showing the buccal alveolar crest *(BC)* and the cementoenamel junction *(CEJ)* before **(D)** and after **(E)** facial displacement (day 150). *BC_2* and *BC_3* represent the buccal alveolar crest of ^{2}I and ^{3}I. **F,** Radiograph showing reestablished bone height (*BC*) in the tooth moved back to its original position. *(Adapted from Thilander B, et al: Bone regeneration in alveolar bone dehiscences related to orthodontic tooth movements,* Eur J Orthod *5:105, 1983.)*

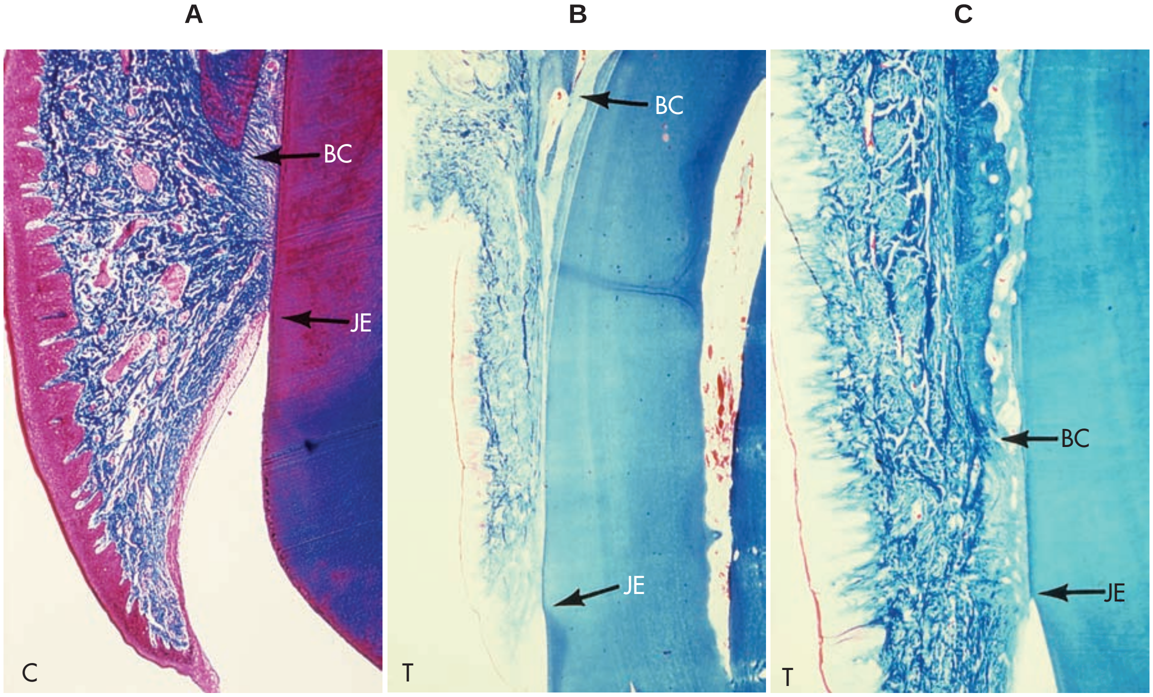

FIGURE 9-38 Histologic specimens of **(A)**, a control tooth *(C)* that was not moved and **(B and C)** a test tooth *(T)* first moved labially and then back again for a total of 300 days. Note the same distance between the buccal alveolar crest *(BC)* and the epithelial junction *(JE)* in the test and control teeth. *(Adapted from Thilander B, et al: Bone regeneration in alveolar bone dehiscences related to orthodontic tooth movements,* Eur J Orthod *5:105, 1983.)*

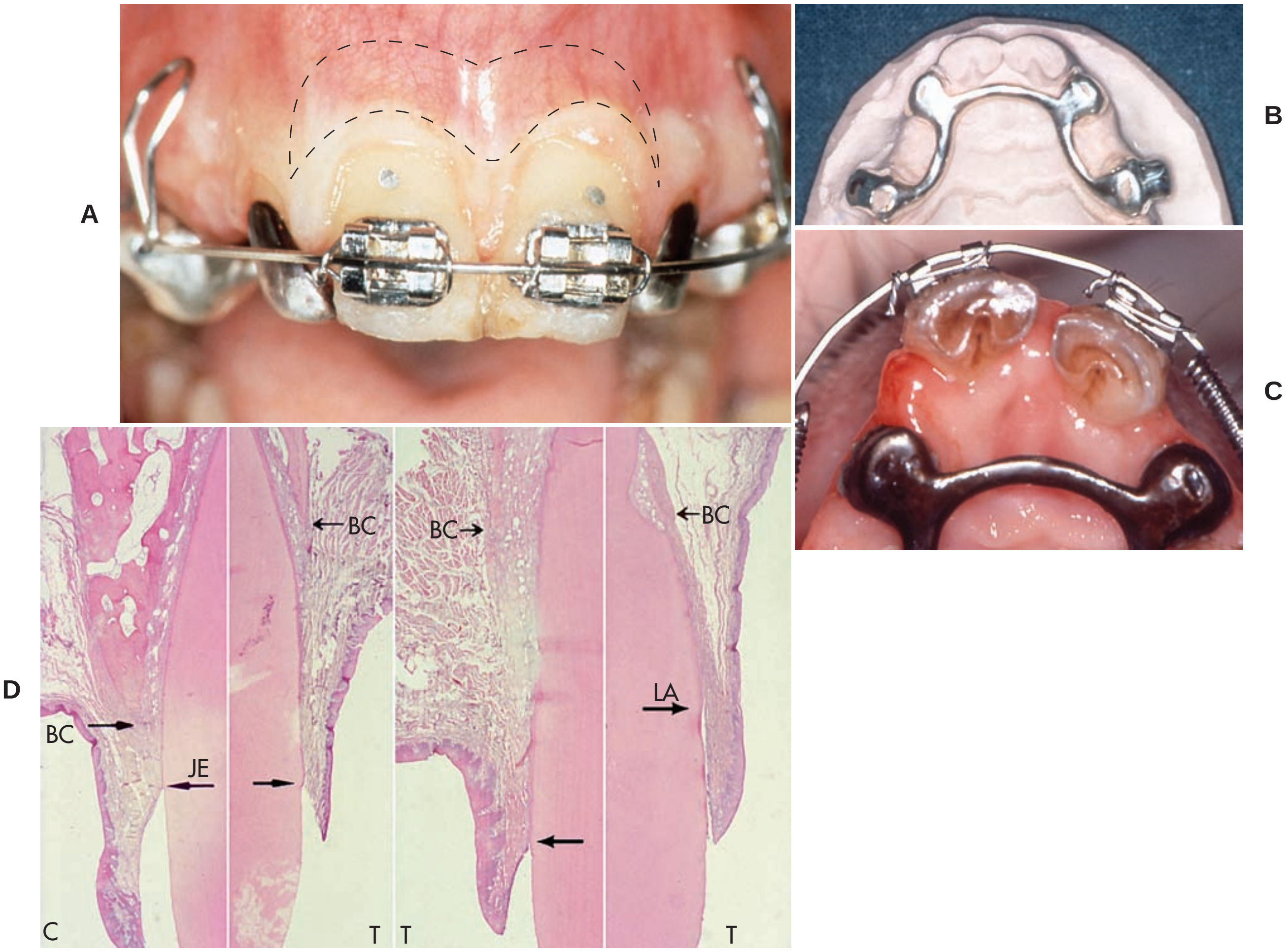

FIGURE 9-39 Incisors moved into areas with various thickness of gingiva. **A,** The volume of the keratinized gingival was surgically reduced to different degrees on left and right sides of the incisors. **B,** Orthodontic appliance used for labial displacement. **C,** The amount of labial tooth movement. **D,** Histologic specimens showing normal bone height and soft tissue margin at a control tooth *(C)* but reduced bone height and soft tissue margin at three test teeth *(T)*. *JE*, connective tissue attachment; *BC,* bone crest; *LA*, loss of attachment. *(From Wennström J, et al: Some periodontal tissue reactions to orthodontic tooth movement in monkeys,* J Clin Periodontol *14:121, 1987.)*

An interesting finding was that the newly formed bone on the pressure side showed resorption on the surface near the root and apposition on the opposite side of the thin bone plate (Figure 9-41, *C*), which was interpreted as a piezoelectric effect through strain-generated potentials, arising as a result of mechanically induced deformation of collagen or hydroxyapatite crystals.[31]

This experimental model has been tested in partially edentulous patients with normal periodontal tissue support located adjacent to an area with reduced bone volume.[32] Teeth have been moved orthodontically between 5 and 8 mm into such an area with maintained support and used as abutment for a fixed prosthetic denture (Figure 9-42). A dental implant placed in the created space showed excellent bone integration (Figure 9-43). The results of these clinical follow-up studies are encouraging, as long as bodily tooth movements with light orthodontic forces are used. How far a tooth can be displaced into such an area can only be speculated.

Transmission of Orthodontic Forces into Cellular Reaction

The old observation by Reitan illustrates well one of nature's wonders[7] (Figure 9-44). The tooth is being moved in the direction of the arrow. Resorption of the alveolar bone wall has occurred. Fatty bone marrow has been changed into red bone marrow. At a little distance behind the alveolar bone wall, a new bony lamella is laid. How do the different cells know that they should react and in a special way? Tooth movement involves two interrelated processes: the bending of alveolar bone and remodeling of the periodontal tissues. Many mechanisms, exemplified in the following paragraphs, are considered responsible for the differentiation of cells incident to the application of an orthodontic force.

Bending of the alveolar bone give rise to electrical potentials, responsible for regulating osteogenesis (tension side) and bone resorption (compression side). *Piezoelectricity* is an electric charge produced by the

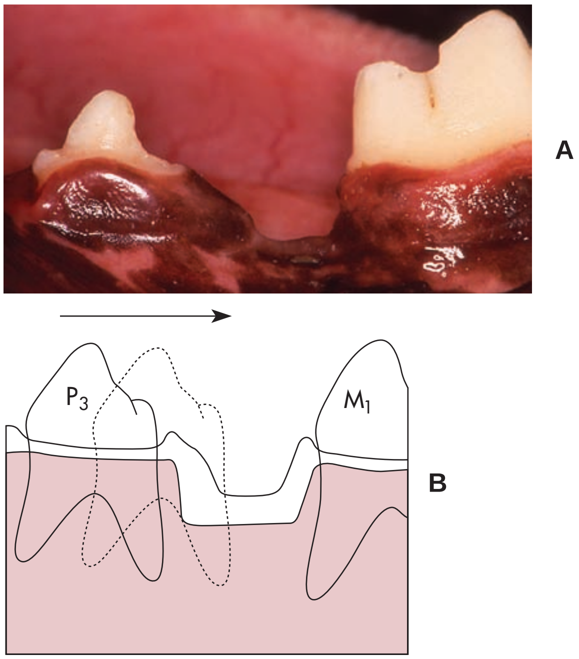

FIGURE 9-40 Clinical photograph **(A)** and schematic drawing **(B)** illustrating the bodily movement of the third premolar in the dog into an area with reduced alveolar bone height. *(From Lindskog-Stokland B, et al: Orthodontic tooth movement into edentulous areas with reduced bone height. An experimental study in the dog,* Eur J Orthod *15:89, 1993.)*

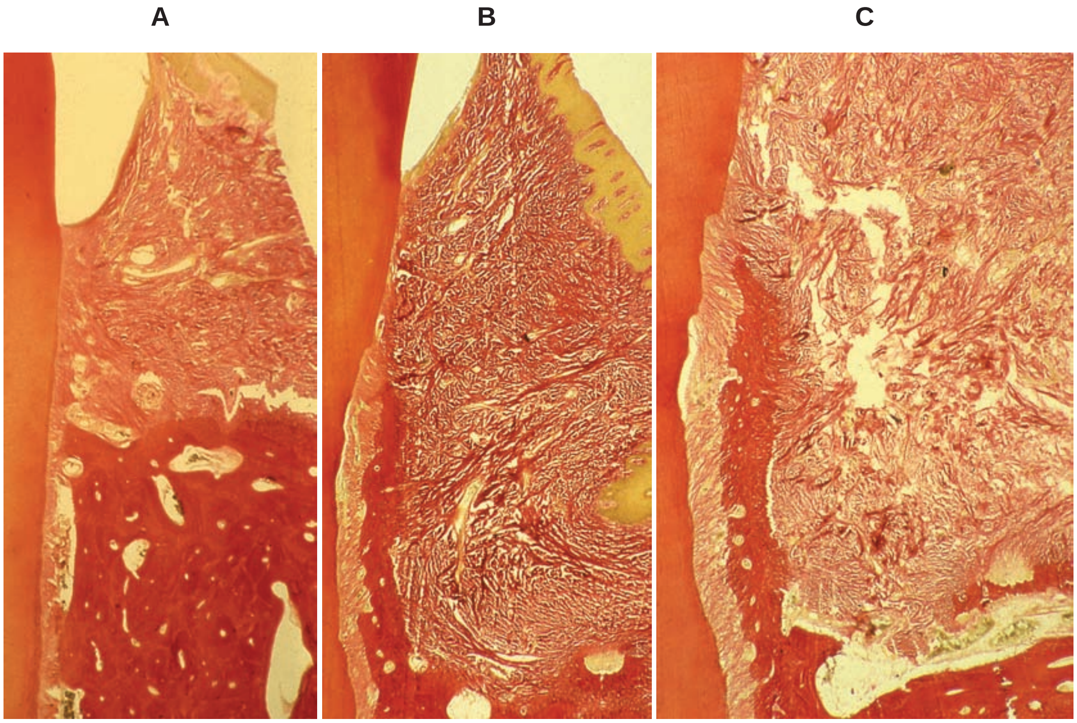

FIGURE 9-41 Specimens from a control (unmoved tooth) **(A)** and a tooth moved as shown in Figure 9-40 **(B). C,** The bone tissue in the coronal part of the root showed a large number of cells in contrast to the compact appearance of the more apically located bone. *(From Lindskog-Stokland B, et al: Orthodontic tooth movement into edentulous areas with reduced bone height. An experimental study in the dog,* Eur J Orthod *15:89, 1993.)*

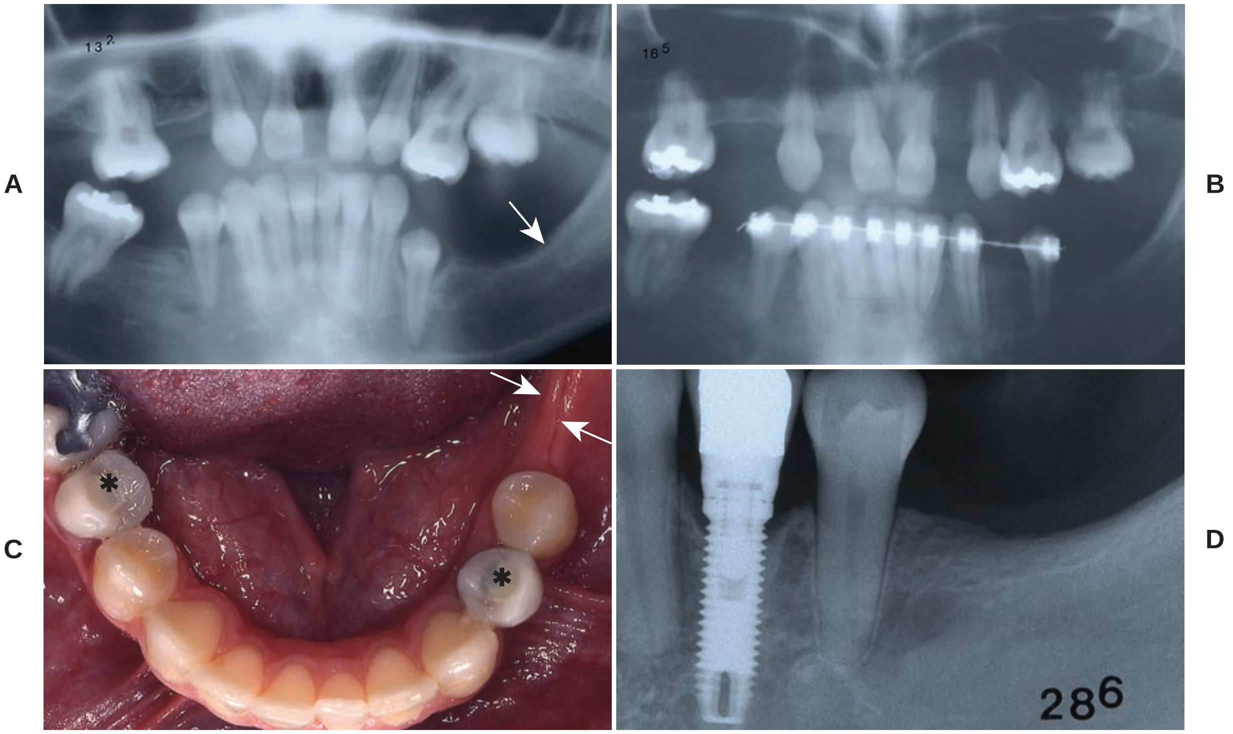

FIGURE 9-42 A 25-year-old man who is partially edentulous because of trauma. **A, B,** Marked bone loss *(arrows)* in the left maxillary alveolar process. **C,** The second premolar was moved bodily one cusp width into the area with reduced bone support. **D,** After a treatment period of 12 months a prosthetic bridge was constructed. Note the regaining of alveolar bone. *(From Thilander B: Infrabony pockets and reduced alveolar bone height in relation to orthodontic treatment,* Semin Orthod *2:55, 1996.)*

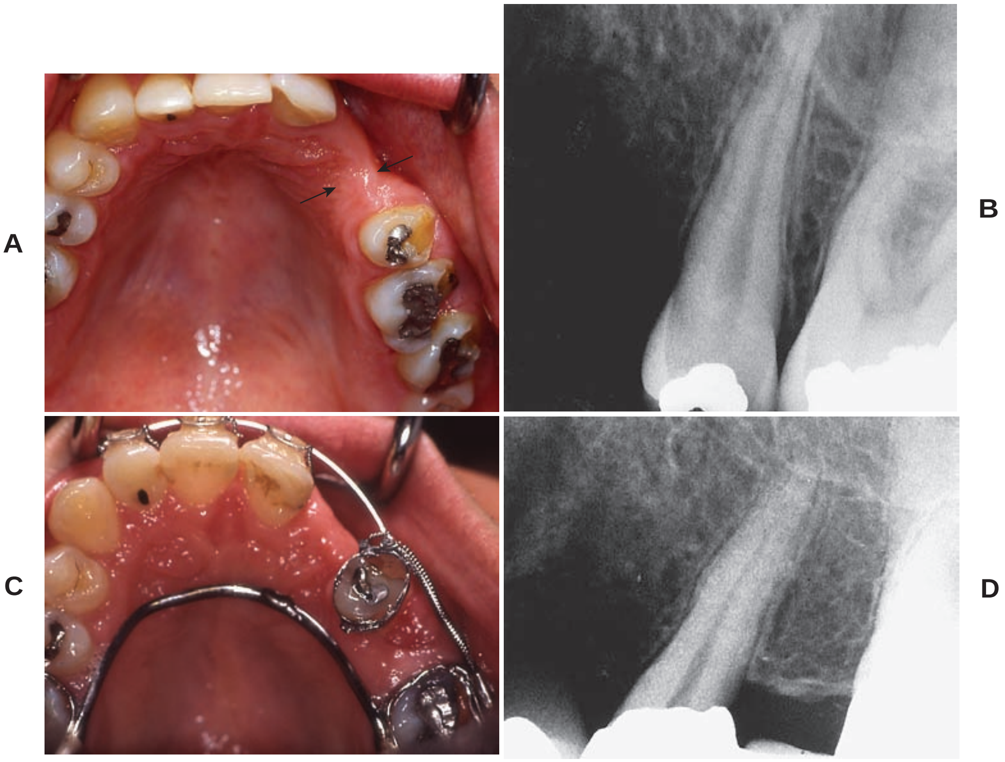

FIGURE 9-43 **A,** Radiograph of a 13-year-old girl with 12 congenitally missing teeth. In the mandible, it was decided to align the dental arch and to place an implant in the right premolar region. On the left side, implant placement was contraindicated because of thin bone volume in the buccolingual direction. **B,** Instead, the first premolar was moved one cusp width distally, and an implant was placed in the created space at age 17 years. **C,** Note the thin buccolingual bone volume in the lower left side *(arrows)* posterior to the distalized premolar. The implant-supported crowns are indicated by asterisks. **D,** At the last observation, a good result was registered with excellent bone integration of the implants. *(From Thilander B, et al: Orthodontic aspects on the use of oral implants in adolescents: a 10-year follow-up study,* Eur J Orthod *23:715, 2001.)*

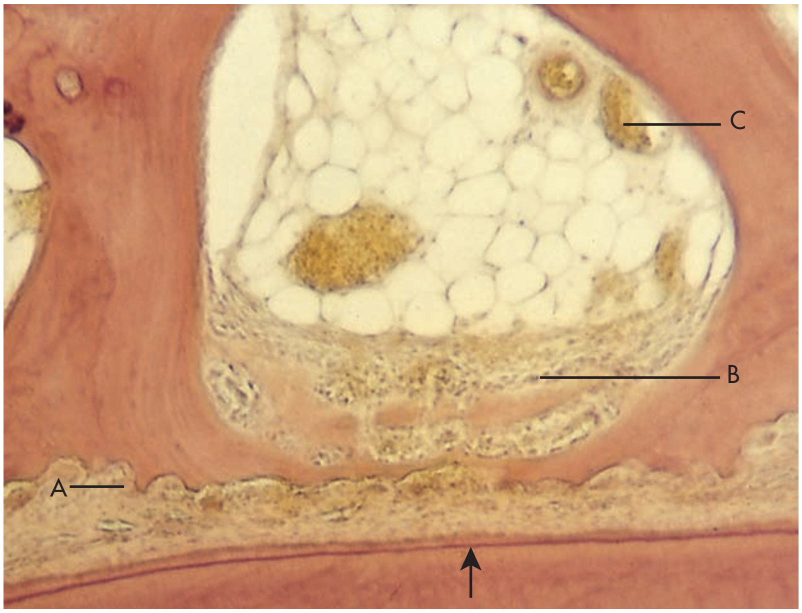

FIGURE 9-44 Bodily movement of an upper second incisor in a dog. The *arrow* indicates the tooth and direction of movement. The root was moved against a space containing fatty marrow, which was transformed into loose fibrous tissue in advance of the movement. The periodontal space is narrower in this area because the uncalcified bone layer along the inside of the marrow space is less readily resorbed by osteoclasts. *A,* Direct bone resorption, one of the many Howship lacunae with osteoclasts. *B,* Compensatory bone formation; osteoid layer bordered by osteoblasts. *C,* Capillary surrounded by fatty marrow.

deformation of crystalline structures such as hydroxyapatite, collagen, and fibrous proteins.[31] It has, however, been questioned whether electrical phenomena are able to regulate the metabolic activity of cell types as different as osteoblasts and osteoclasts. Today we have learned more about cell–cell and cell–matrix interactions and that mechanical strain activates multiple cell signaling pathways, as exemplified later.

Orthodontic mechanical stress may induce localized cells to synthesize *prostaglandins,* which stimulate osteoclastic bone resorption in the remodeling process.[33] Local prostaglandin injections hence might increase the rate of tooth movement.

The perturbation of periodontal cells as a result of orthodontic forces may change the influx of *calcium* and *sodium ions* into the cells, which in turn alters the production of the "secondary cell messengers" *cyclic adenosine monophosphate* and *cyclic guanosine monophosphate* (cAMP and cGMP, respectively). Low levels of cAMP and cGMP influence the differentiation of cells for bone production.[34] An increase in the number of cAMP-positive cells in areas of the PDL was observed, where bone resorption or deposition subsequently occurred.[35] Osteocytes in the adjacent alveolar bone, however, appeared to be relatively unaffected by the mechanical force.

An increase in cAMP and cGMP in periodontal cells does not result solely from the direct effects of the mechanical forces but also from endogenous signaling agents in the *nervous* and *immune systems*.[36] Neuropeptide acts as a neurotransmitter from sensory nerve fibers in the PDL and supply a link between physical stimulus and the biochemical response. Pain-sensitive nerve endings release stored substance P into the PDL, leading to binding of substance P to specific cellular receptors, particularly alveolar bone osteoblasts, and through interaction with endothelial cells to rapid vasodilation.

Integrin receptors link actin-associated cytoskeletal proteins with the extracellular matrix as well as with adhesion molecules on the surface of adjacent cells.[37] Integrins are therefore ideally sited to mediate the transmission of bidirectional forces across the cell membrane.[38] Numerous signaling pathways are activated by integrins, which play roles in cell migration, proliferation, and differentiation.

Many *cytokines* play important roles in regulating connective tissue turnover and in bone remodeling during orthodontic tooth movement. They are low-molecular-weight proteins produced by cells that regulate or modify the action of other cells in an autocrine or paracrine manner. The definition includes the interleukins (ILs), tumor necrosis factors (TNFs), RANKL (a member of the TNF family), interferons, and growth factors. Application of orthodontic stress causes a significant increase in the staining intensity of IL-1 in all cell types of PDL, particularly in osteoblasts in tension sites and osteoclasts at compression sites.[39] Cytokines, produced by mechanically activated cells, hence are responsible for mediating both the resorptive and formative phases in tissue remodeling.

In conclusion, many mechanisms are considered responsible for the differentiation of cells incident to the application of an orthodontic force. Orthodontic tooth movements may show local traits of a damage/repair process with inflammation-like reactions: high vascular activity, many leukocytes and macrophages, and involvement of the immune systems. Local overstretching and overcompression (hyalinization) must be minimized, particularly in areas of thin cortical bone.

Many mechanisms are considered responsible for the differentiation of cells incident to the application of an orthodontic force.

TISSUE RESPONSE IN SUTURES

The effect of mechanical forces on the craniofacial sutures has been well described in the literature. Controlled forces generated by various types of headgear and appliances for palatal expansion have shown cephalometric changes of the craniofacial morphology. The changes are, however, of different degree, and contradictory findings regarding long-term stability have been reported. One explanation of these different opinions is that the position, orientation, and even the numbers of facial sutures seem to be closely oriented with respect to various forces (Figure 9-45).

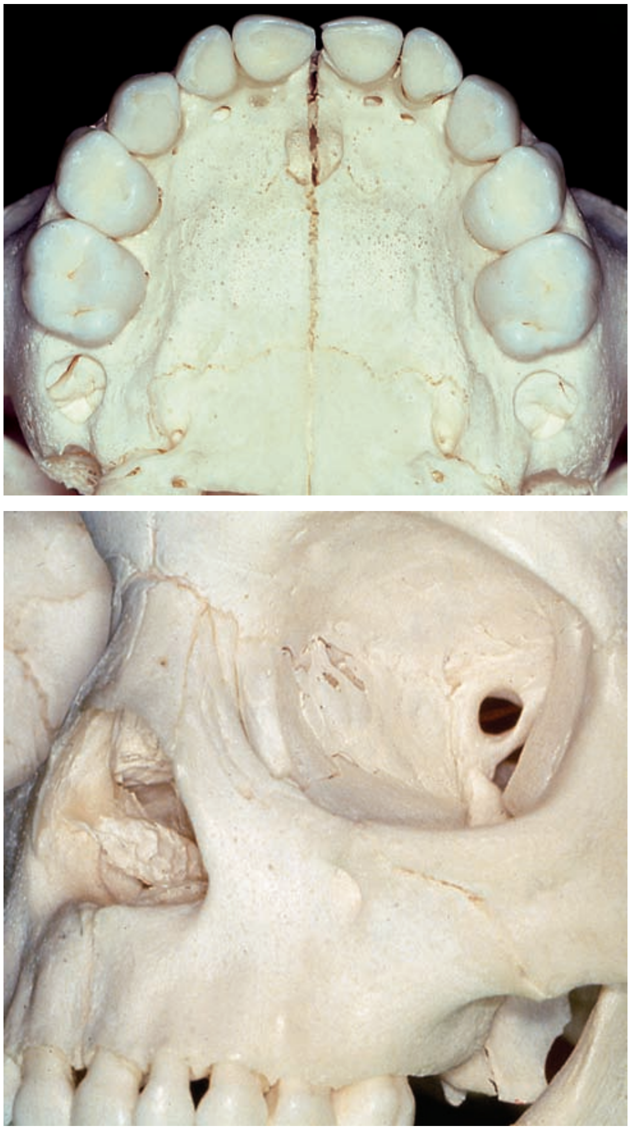
FIGURE 9-45 Cranium showing the sutural system of the maxilla.

The possibility of influencing the basal parts of the nasomaxillary complex is an open suture before any bony union (synostosis) has been established. However, different opinions about the age of human suture closure are prevalent, and the mechanism of physiologic fusion of sutures is still obscure. Histologic studies on human maxillary sutures[40,41] have shown that palatal suture closure usually starts during the third decade of life, although with large individual variations. After adolescence, closure was observed in most specimens, indicating a rapid increase in fusion during the third decade. Based on microradiograms of the frontozygomatic suture in humans, Kokich[42] concluded that most facial sutures remain visible until the eighth decade of life.

Structure of the Suture. Sutures consist of a fibrous tissue with osteogenic layers on both surfaces (Figure 9-46). Sutures therefore represent an extension of the periosteal layer of the bone and participate in the design of the bone by their remodeling capacity. The fiber system is mainly collagenous with a rapid synthesis and turnover. Elastic fibers are more frequent in sutures than in the PDL.

The maturing suture tissue in the growing individual demonstrates changes with age that eventually end with a bony obliteration of the sutural space (Figure 9-47). The density and thickness of the fibrous component increase with age, and when growth ceases, bundles of fibers can be seen running transversely across the suture,

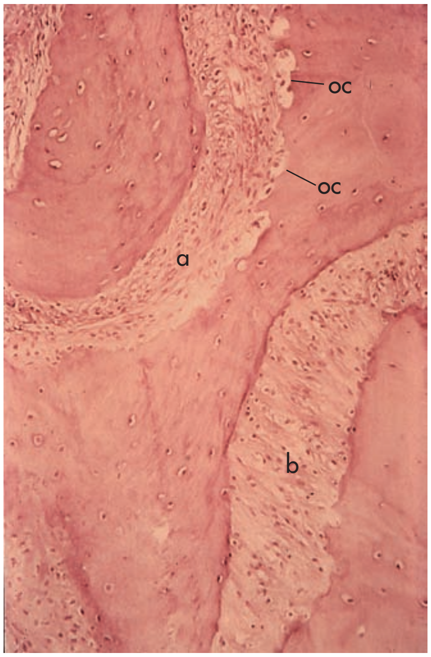

FIGURE 9-46 Photomicrograph of the intermaxillary suture of a 12-year-old boy. Variation in the fiber structure is evident; cells and fibers parallel *(a)* and perpendicular *(b)* to the bony surface. Note the osteoclasts *(oc)*. *(From Persson M, Magnusson B, Thilander B: Suture closure in rabbit and man: a morphological and histochemical study,* J Anat *125:313, 1978.)*

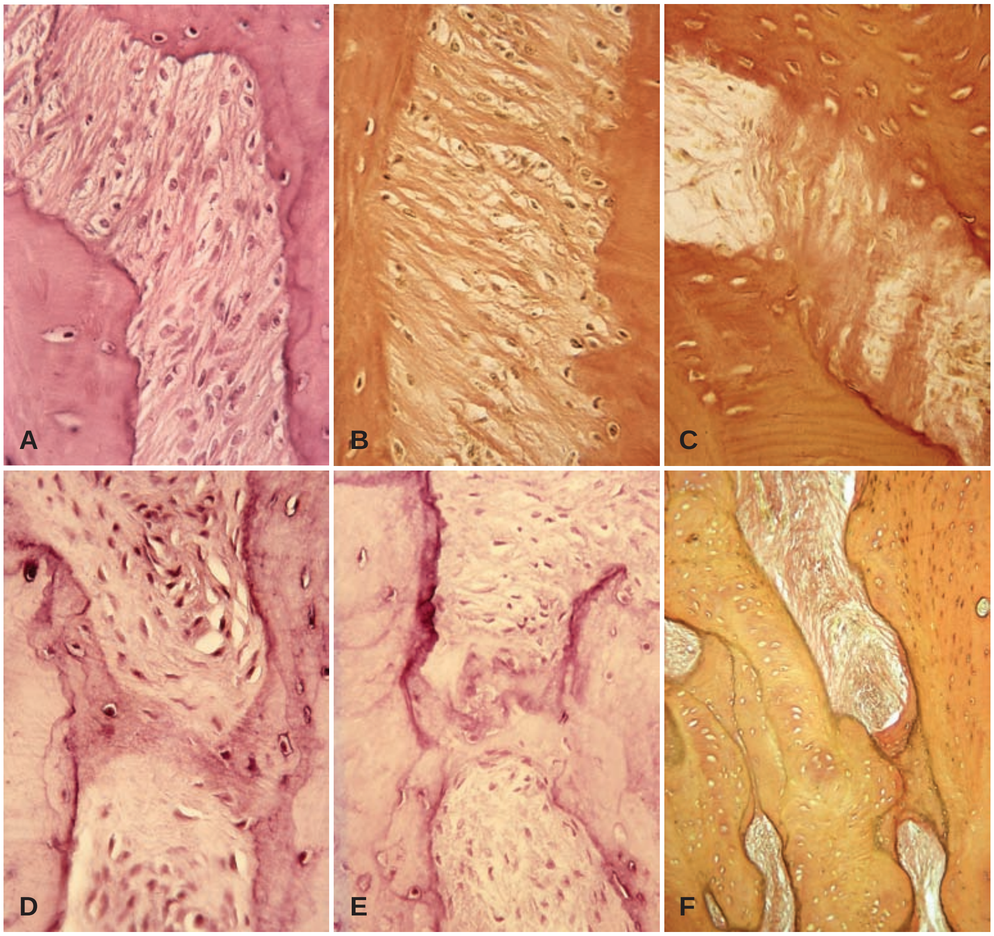

FIGURE 9-47 Photomicrographs from the human intermaxillary suture at different ages (14 to 25 years) showing various stages of fusion. The collagen fibers perpendicular to the bony surface **(A)** increase in thickness **(B)** and density **(C)** with age. A slender bridge of uncalcified tissue in the area of tightly packed fibers (**D** and **E**) is a preliminary stage to bony obliteration **(F)** of the suture. *(Adapted from Persson M, Magnusson B, Thilander B: Suture closure in rabbit and man: a morphological and histochemical study,* J Anat *125:313, 1978.)*

increasing the mechanical strength of the joint. Osteogenesis tends to be restricted to areas of transversely densely arranged collagen bundles, a preliminary stage to bony bridgings.[43] Because of the serpentine course of the suture, areas of tension and compression develop in the tissue (Figure 9-48).

Concomitant with a general advance of obliteration with age in a single suture, more of the palatal suture area is involved. Besides variations in the degree of closure between sutures, variations also exist between different parts of the same suture. Closure progresses more rapidly in the oral than in the nasal part of the palatal vault, and the intermaxillary suture starts to close more often in the posterior than in the anterior part.[41] Because of the increased inclusion and bone locking (interdigitation), the possibility for influencing the suture area by orthopedic treatment gradually decreases with age.

Suture Response to Orthodontic/Orthopedic Forces. The attempt to move an incisor orthodontically *through the midpalatal suture* in dogs was shown to be unsuccessful.[44] The histologic analysis revealed that the suture had been dislocated in front of the orthodontically moved incisor (Figure 9-49). Eventually, the PDL and suture tissue became merged, demonstrating an apparently close similarity between the tissues of the two joint types. However, in dogs with a closed suture, the incisor could pass the sutural area without any impediment.

Traction generated by *orthopedic forces* has long been claimed to stimulate sutural growth, and widening of the midpalatal suture is a clinically well-documented procedure in orthodontics (Figure 9-50) (for a review, see Timms[45]). The tissue response has been reported in histologic studies in animals. The mechanical response to traction includes a widening of the suture and changes in the orientation of fiber bundles.[46] A considerable increase of osteoblasts and an osteoid zone on both sutural bone surfaces indicate bone formation (Figure 9-51). The bone deposition accompanies traction, allowing the suture to recover a normal histologic picture. A positive correlation exists between the magnitude of the tensile force and osteogenic response.[47,48] Experiments in vitro verify that mechanical tensile forces stimulate synthesis of structural proteins.[49] *Healing* of a suture after rapid expansion may entail formation of bony bridges across the suture. Low-power laser irradiation has been shown to accelerate bone regeneration in the midpalatal suture during rapid palatal expansion in the rat.[50]

The *transduction of a mechanical force* into bone production may involve an intracellular influx of calcium

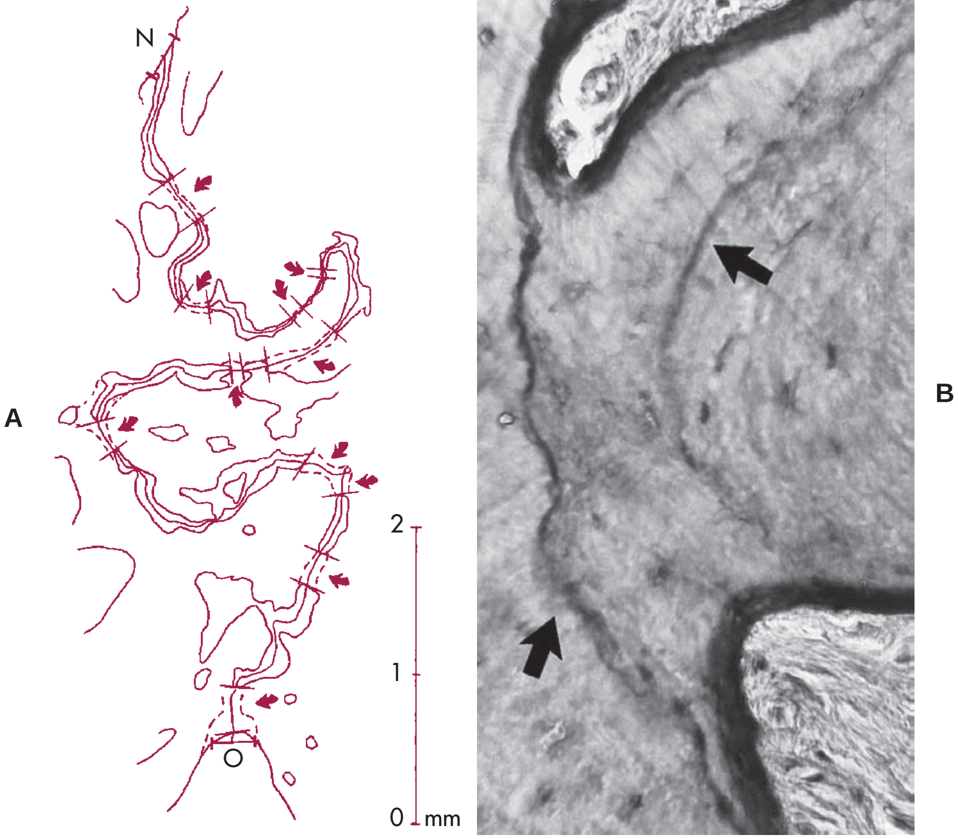

FIGURE 9-48 **A,** Tracing of a section in the frontal plane from the posterior part of the intermaxillary suture of a 31-year-old man. Nasal *(N)* and oral *(O)* sides are presented. Bony bridges occur at the arrows. **B,** An ossified part of the suture. Note the basophilic staining at the site of the earlier resting-suture margin (*arrows*). *(From Persson M, Thilander B: Palatal suture closure in man from 15 to 35 years of age,* Am J Orthod *72:42, 1977.)*

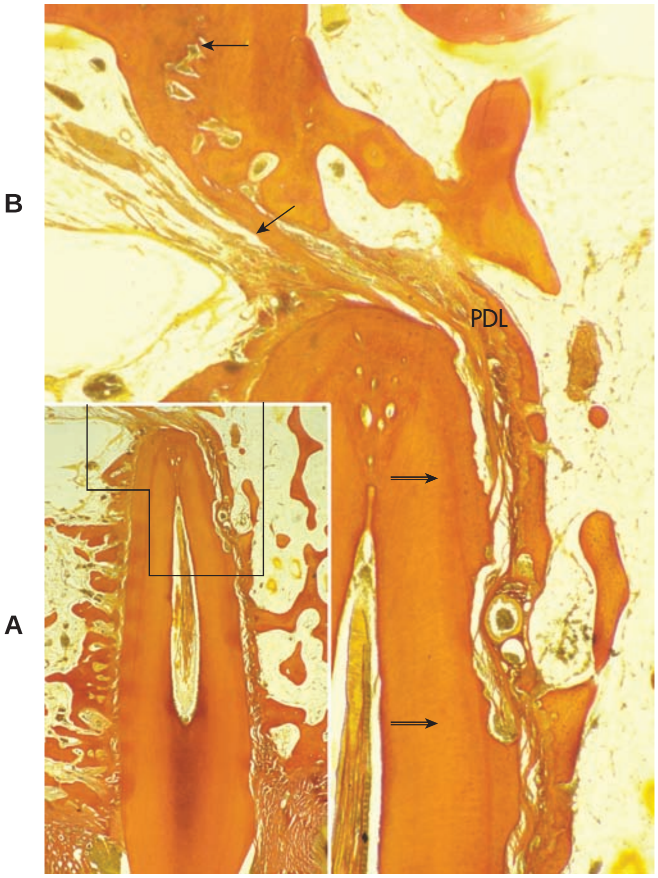

FIGURE 9-49 Photomicrographs of the intermaxillary suture of a young dog in which an attempt to orthodontically move an incisor through the suture was shown to be unsuccessful. **A,** The suture fibers are stretched around the apex and seem to continue in the periodontal ligament *(PDL)*. **B,** Magnification of boxed area in **A**. *Closed arrows* indicate the intermaxillary suture; open arrows indicate the direction of movement with root resorption. *(From Follin M, Ericsson I, Thilander B: Orthodontic tooth movement of maxillary incisors through the midpalatal suture area. An experimental study in dogs,* Eur J Orthod *6:237, 1984.)*

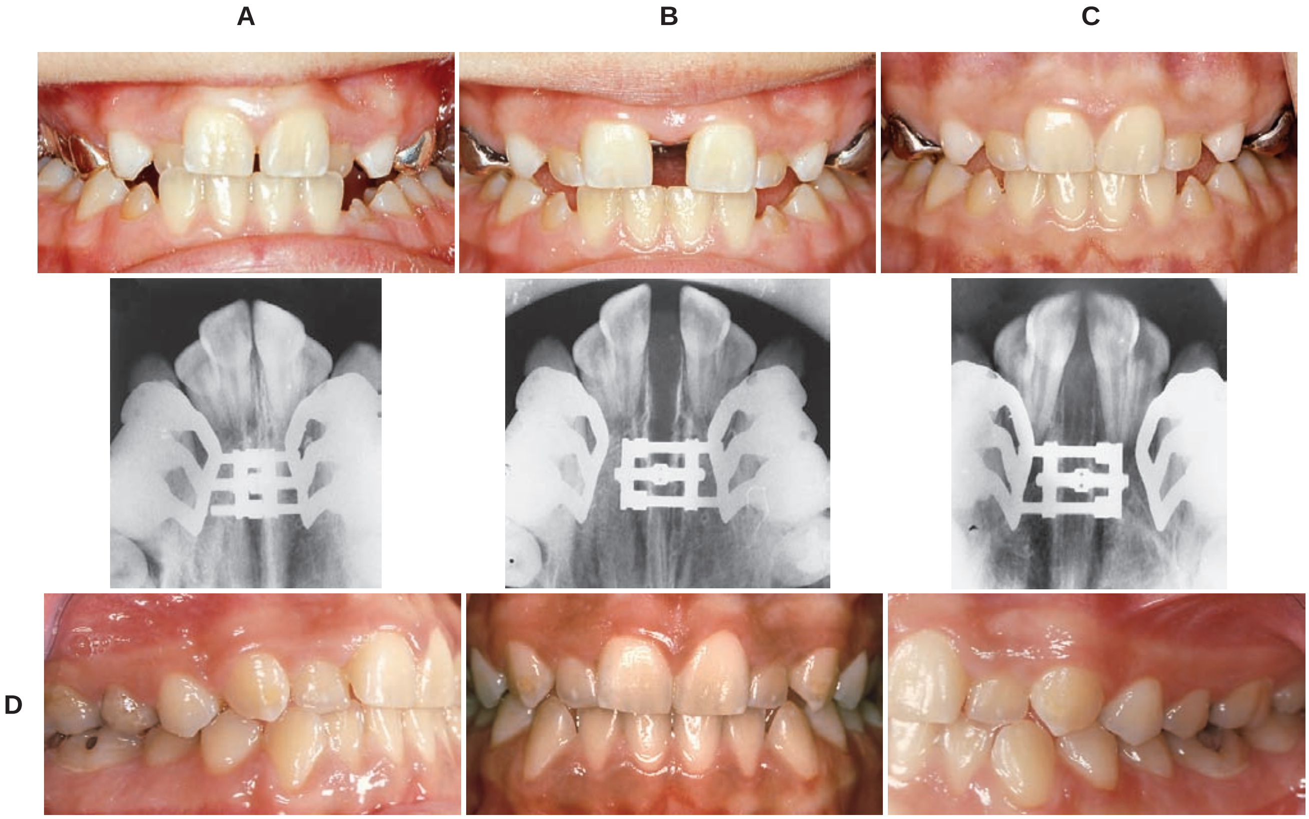

FIGURE 9-50 Widening of the midpalatal suture in a 12-year-old girl. **A,** Before maxillary expansion; **B,** after 21 days of rapid maxillary expansion; **C,** spontaneous closure at day 60, when the appliance was removed; **D,** 5 years postretention.

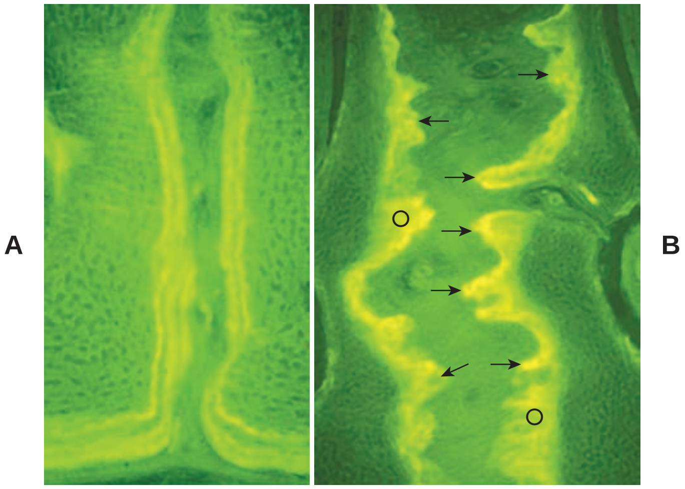

FIGURE 9-51 Photomicrographs of the intermaxillary suture in the rat. **A,** Before expansion; **B,** after sutural expansion for 7 days. Increased cellular activity is evident along the total bone surfaces *(arrows). O,* Osteoid layer in the yellow areas (tetracycline administration). *(From Engström C, Thilander B: Premature facial synostosis: the influence of biomechanical factors in normal and hypocalcemic young rats,* Eur J Orthod *7:35, 1985.)*

and/or sodium ions, which decreases cAMP and triggers DNA synthesis and cellular proliferation.[34] Ten Cate et al.[51] used heavy forces to expand cranial sutures and showed that fibroblasts must proliferate and repair sutural connective tissue before osteogenesis and remodeling of the suture take place.

Rapid maxillary expansion is an orthopedic procedure that has been shown to influence not only the midpalatal suture but also the *circumaxillary sutural system*. In such a palatal splitting, most of the resistance to separation results from the circumaxillary structures. Because posterior and anterior *displacements of the maxilla* (*distraction*) involve more sutures than displacements caused by palatal expansion, the resistance to separation consequently increases (see Figure 9-47). Therefore, orthopedic forces have to be applied after surgical opening of suture.

TISSUE RESPONSE IN THE TEMPOROMANDIBULAR JOINT

The response in the TMJ region to functional and orthopedic appliances has been a subject of discussion for many years. So, it is necessary to understand the nature

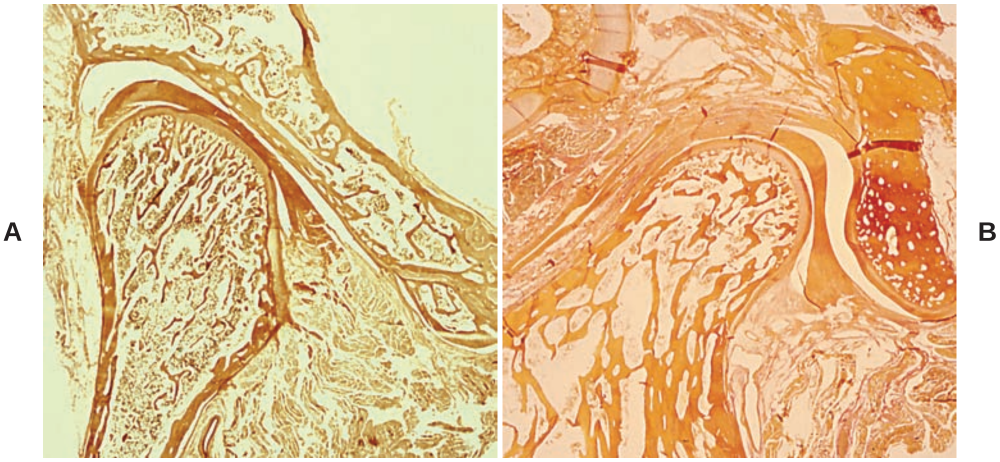

FIGURE 9-52 Photomicrographs of the human temporomandibular joint. **A,** Transverse plane; **B,** sagittal plane. *(From Thilander B, Carlsson GE, Ingervall B: Postnatal development of the human temporomandibular joint. I. A histologic study,* Acta Odont Scand *34:117, 1976.)*

of the tissues that make up the TMJ, their relation to the normal growth process, and the manner in which they express themselves during maturation.

The TMJ provides the essential functional connection between the cranium and the upper and lower jaw (Figure 9-52). However, the primary functions of the TMJ in general and the mandibular condyle in particular are not simple, and they change during development. Furthermore, striking differences exist in the extent of mineralization between the condyle and the temporal component (Figure 9-53).

Structure of the Temporomandibular Joint. Several investigations of the anatomy and development of the TMJ in various experimental animals are available. However, there are only a few comprehensive systematic investigations of human postnatal TMJ development.[52–54]

Condylar Cartilage. The condylar cartilage varies in appearance from one part of the condyle to another and its histomorphologic picture varies from birth to childhood, but the following four layers usually can be seen (Figure 9-54): a fibrous connective tissue layer (surface articular zone); a highly cellular intermediate layer containing proliferating cells (proliferative zone); a cartilage layer with irregularly arranged chondrocytes (hypertrophic zone); and a zone with endochondral bone ossification (bone formative zone).

During the juvenile period, the condyle becomes progressively less vascularized and the entire growth cartilage layer becomes significantly thinner, primarily because of reduction in the hypertrophic zone. At the age of 10 years, the mandibular condyle is characterized by a relatively thick articular tissue layer, progressive reduction in the size of the entire growth cartilage layer, and evidence of increased mineralization in the deeper portion of the hypertrophic zone. After 13 to 15 years, the cartilage layer decreases further in thickness. By the age of 19 to 22 years, only islands of cartilage cells remain in the superior and anterior regions.

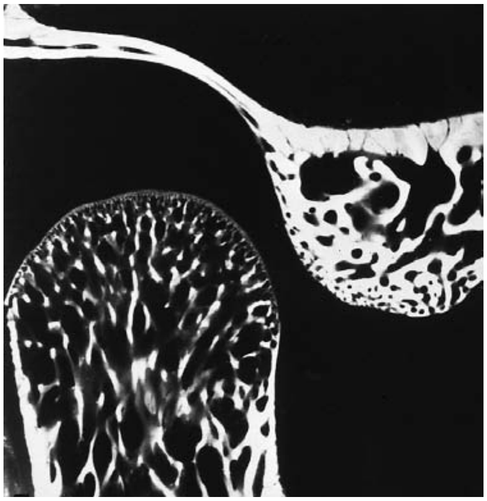

FIGURE 9-53 Microradiogram of a sagittal section of the temporomandibular joint from a 6-year-old boy. Note the difference in mineralization in the different parts of the joint. *(From Ingervall B, Carlsson GE, Thilander B: Postnatal development of the human temporomandibular joint. II. A microradiographic study,* Acta Odont Scand *34:133, 1976.)*

Mandibular Neck. The fibrous layer of the condylar cartilage is continuous with the periosteum of the ramus, and remodeling processes are seen in all regions of the mandibular neck (Figure 9-55). The term *condylar growth* is therefore misleading, and the term *ramus and condylar growth* is more correct, as expressed by Enlow.[55]

Temporal Component. The S-shaped curve that characterizes the temporal component of the TMJ becomes evident during the first 6 months of life. The articular surface is lined with a fibrous connective tissue resembling the surface articular zone of the condyle (Figure 9-56, *A*), with an increase in thickness during early and mixed dentitions through puberty. The proliferating zone is seen up to the age of 17 to 18 years

(Figure 9-56, *B*). In the fossa, remodeling is observed from early childhood to adulthood[53] (Figure 9-56, *C* and *D*).

Temporomandibular Joint Response to Orthopedic Forces. Because remodeling processes are seen in all components of the joint, most obviously in young ages, it has been speculated whether the TMJ would respond to orthodontic stimuli and influence the growth of the mandible.[56] McNamara[57] has shown that the TMJ in monkeys is capable of functional adaptation when the mandible is displaced in a *forward direction*. Hypertrophy and hyperplasia of the prechondroblastic and chondroblastic layers of the condylar cartilage were seen, particularly along the posterior border of the condyle, with rapid bone formation in the condylar head. After about 10 weeks, the generalized proliferation of the condylar cartilage was, however, no longer evident, indicating that the essential remodeling had been completed. Furthermore, an increased activity of the superior head of the lateral pterygoid muscle was recorded. A progressive modification of the neuromuscular pattern thus was observed with the skeletal adaptation to the forward displacement of the mandible. Moreover, the subperiosteal growth rate increases at the posterior border of the ramus. In addition, the bone turnover rate and mineralization in the mandible as a whole are significantly influenced.

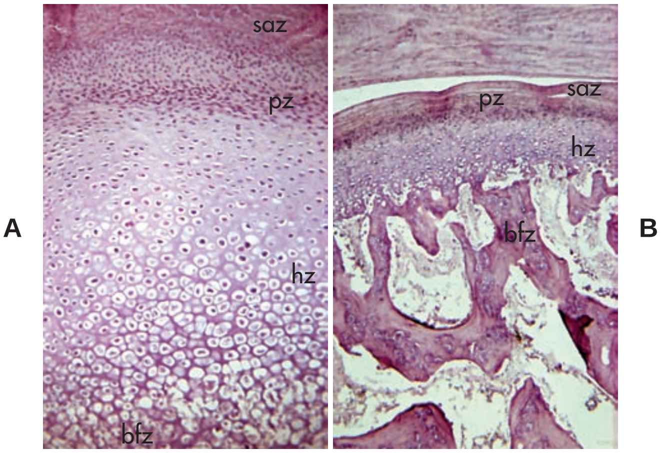

FIGURE 9-54 Photomicrographs of the condylar layer from the upper central part of the condyle (sagittal plane), showing the different morphology at various ages (×100). **A,** A 6-month-old boy. **B,** A 12-year-old boy. *saz,* Surface articular zone; *pz,* proliferation zone; *hz,* hypertrophic zone; *bfz,* bone formation zone. *(Adapted from Thilander B, Carlsson GE, Ingervall B: Postnatal development of the human temporomandibular joint. I. A histologic study,* Acta Odont Scand *34:117, 1976.)*

Petrovic and coworkers have shown in a number of experiments in rats, with anterior displacement of the mandible, that a functional appliance primarily induces an amplification in skeletoblast and prechondroblast mitotic activity, an acceleration in differentiation of skeletoblasts into prechondroblasts, an increase in transformation of prechondroblasts into functional chondroblasts, and an acceleration in chondroblast hypertrophy and endochondral bone growth (for a review, see Petrovic et al.[58]).

A *mandibular retrusion* by chin cap therapy in the rat revealed a reduced thickness of the prechondroblastic zone and a decrease in the number of dividing cells.[59] A reduced length of the mandible indicated that chin cap treatment had a retarding effect on mandibular growth, contrary to the increased length in the experiments with anterior displacement of the mandible.

How does this experimentally induced stimulation or retardation of condylar growth relate to *clinical orthodontics*? Some researchers maintain that mandibular growth in children can be altered and that this change can be detected through well-designed clinical procedures. However, several researchers consider that the therapeutic effect of a functional appliance on the lengthening of the mandible is not clinically relevant, for the individual growth potential during the treatment period also is included in this effect.

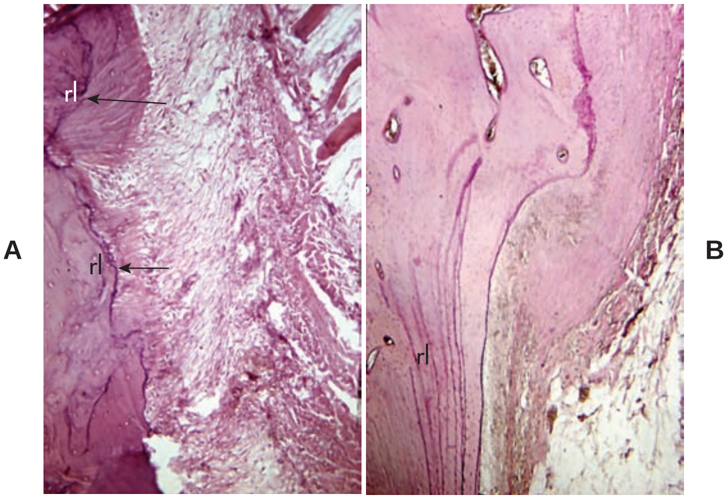

FIGURE 9-55 Photomicrographs from the mandibular neck (transversal plane) illustrating the remodeling processes (×40). **A,** A 7-year-old girl; **B,** a 23-year-old woman. *rl,* Resting lines. Apposition starts medially to *rl* (*arrows*). *(Adapted from Thilander B, Carlsson GE, Ingervall B: Postnatal development of the human temporomandibular joint. I. A histologic study,* Acta Odont Scand *34:117, 1976.)*

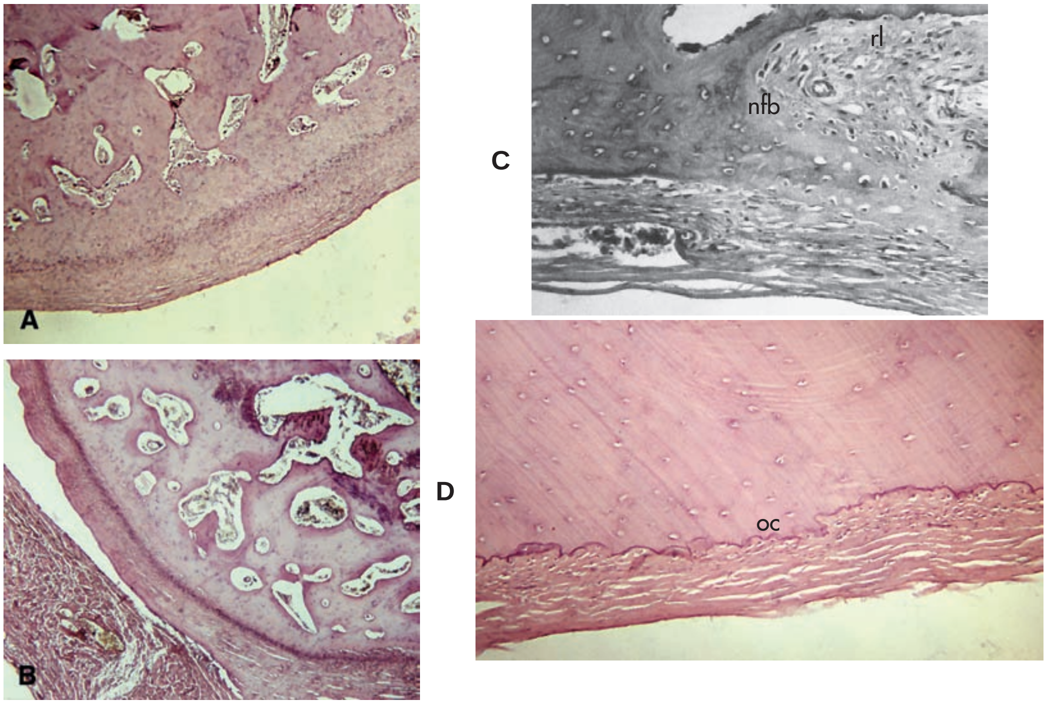

FIGURE 9-56 **A–B,** Photomicrographs from the temporal part (central section, sagittal plane) (×40) articular tubercle of **A,** 9-year-old boy, and **B,** a 14-year-old boy. *saz,* Surface articular zone; *pz,* proliferation zone. **C–D,** Articular fossa illustrating remodeling processes in **C,** a 7-year-old boy, and **D,** a 16-year-old boy. *rl,* Resting line; *nfb,* newly formed bone; *oc,* osteoclastic activity. *(Adapted from Thilander B, Carlsson GE, Ingervall B: Postnatal development of the human temporomandibular joint. I. A histologic study,* Acta Odont Scand *34:117, 1976.)*

These conflicting observations made in clinical studies over many years suggest that alterations in condylar growth in human patients are difficult to document. One reason for this is that the controlled design in animal experiments is hardly attainable in humans. Moreover, the growth rate in the rat and monkey is much faster than that in humans, factors that make appearance and quantification of the adaptive changes difficult. In addition, the clinician is aiming at changing an abnormal growth pattern into a normal one, which is different from alterations that start from normal growth pattern, as in animal experiments. Thus, the question of whether the growth of the human mandible may be altered by orthopedic and functional appliances remains partly unanswered. *However, research shows that the orthopedic change apparently is a combined change of mandibular and temporal components (i.e., condylar and remodeling processes).*

POSTTREATMENT STABILITY

Not all orthodontically achieved changes remain stable. If an undesirable growth pattern is treated partly by influencing growth and partly by compensations in the dentoalveolar system, subsequent posttreatment growth may upset a result that looks good when the patient is young. It is well known that many patients experience changes some years after treatment, which is often described as relapse (i.e., a return toward pretreatment condition). We have, however, to distinguish the "rapid relapse" occurring during the period of remodeling of periodontal structures from the "slow relapse" that is due to the late changes during the postretention period.

Orthodontic Relapse

Experimental studies have shown that if orthodontic movement is not followed by remodeling of the supporting tissues, the tooth will return to its former position.[59–61] The most persistent relapse tendency is caused by the structures related to the marginal third of the root, whereas little relapse tendency exists in the area adjacent to the middle and apical thirds. The effect caused by contraction of the principal and supra-alveolar fibers is shown in Figure 9-57. The crown of an experimentally moved tooth in a dog was moved 2 mm by tipping over during a period of 40 days. After the tooth was released, the degree of relapse movement was recorded graphically. Some relapse was noticed to have already occurred after 2 hours, partly caused by the tooth's regaining a more upright position within the periodontal space. Still more relapse occurred on the following days for a total of about 0.5 mm during 4 days. After this, the tooth came to a standstill. Histologic examination revealed that this was caused by a hyalinized area on the tension side.[61] Therefore, fiber contraction is strong enough to

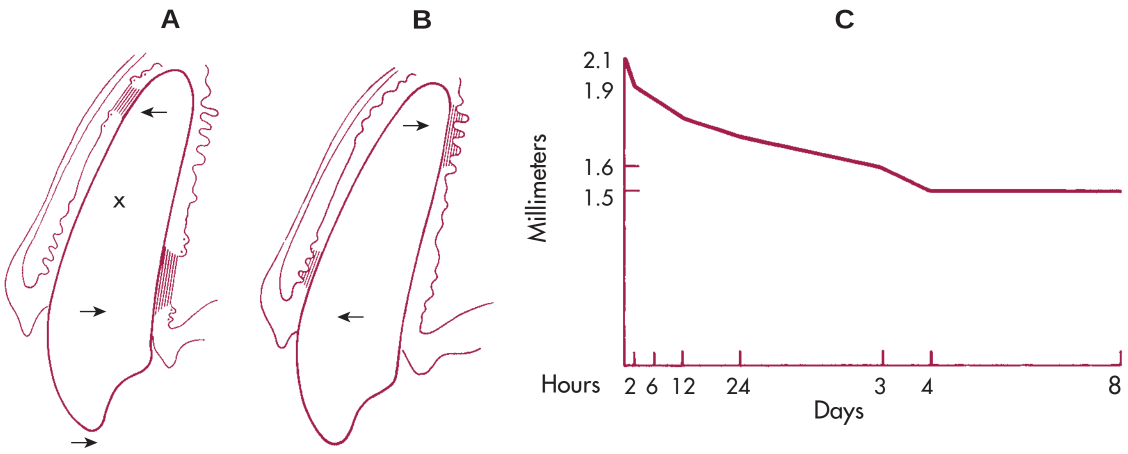

FIGURE 9-57 **A,** Formation of hyalinized areas during tooth movement of an upper second incisor in a dog (duration 40 days). **B,** Formation of hyalinized areas during the relapse period. The tooth was not retained after movement. **C,** Relapse movement during a period of 8 days (as seen in tooth **B**). Hyalinization occurred after 4 days.

produce hyalinization. Similar hyalinized zones may be observed after tipping human teeth without subsequent retention (Figure 9-58).

The tissue reactions in the gingiva differ from those in the PDL and are of different importance for the stability of an acquired tooth position (see Figures 9-2, 9-3, and 9-4). The various fiber groups also respond differently to the remodeling process. Furthermore, the supporting fibrous systems, both supra-alveolar and periodontal, develop during the eruption of teeth according to increasing functional demands. This explains the greater stability of teeth that are guided passively into position during the eruptive period, compared with teeth that are moved after having reached occlusal stability.

Several factors are essential for the reestablishment of an adequate supporting apparatus during and after tooth movements. The main remodeling of the PDL takes place near the alveolar bone; the remodeling of the fibrous system on the tension side is related to the direction of pull on the tooth, resulting in production of new fibers only in that direction.

Unlike the PDL, the supra-alveolar fibers are not anchored in a bone wall that is readily remodeled, and therefore they have less chance of being reconstructed. Furthermore, the remodeling of gingival connective tissue is not as rapid as that of the PDL and the slower turnover of the gingival collagen fibers[34] easily explains why such fibers are seen stretched and unremodeled as long as 232 days after experimental tooth rotation[60] (Figure 9-59). The stretched fiber bundles on the tension side tend to become relaxed and rearranged according to the physiologic movement of the tooth. During retention, new bone fills in the space between the bone spicules. This rearrangement and calcification of the new bone spicules result in a fairly dense bone tissue.[3] Therefore, to avoid relapse, a tooth should be retained until total rearrangement of the structures involved has occurred.

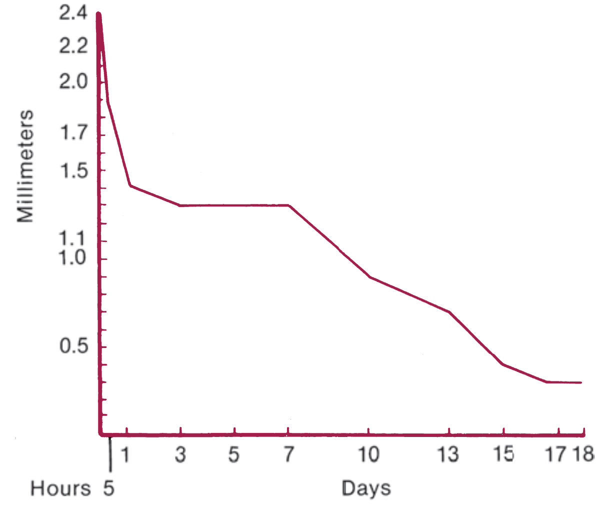

FIGURE 9-58 Degree of movement after labial tipping and the subsequent relapse movement after the tooth had released. Upper lateral incisor of a 12-year-old patient (force, 40 cN). Most of the relapse movement occurred during the first 5 hours. A hyalinized zone existed from the third to the seventh day.

Slower remodeling also explains why surgical pericision of supra-alveolar structures prevents or reduces relapse after the experimental rotation of teeth (see Figure 9-37, *B*). The reason for the slow remodeling of the supra-alveolar tissues after experimental tooth movement probably is related to the quality of particular fiber groups, whose main function is to maintain tooth position and interproximal contact.

A clinical experience is that cases after orthodontical space closure of extraction gaps have a tendency to reopen. The orthodontic force creates a compressed gingival tissue in the extraction site (Figure 9-60, *A*). Excision of this hyperplastic area showed a long-lasting epithelial fold (invagiation) with loss of collagen but an

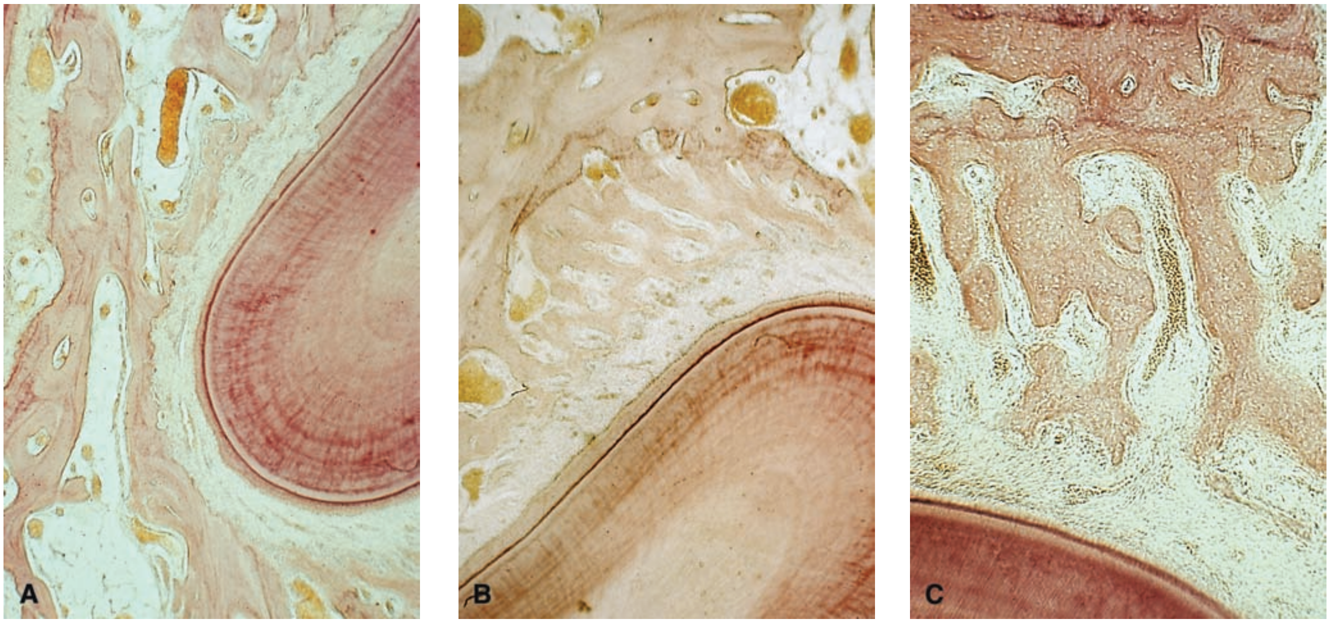

FIGURE 9-59 Tissue response after rotation of a tooth. **A,** Pressure side with direct bone resorption. **B,** Arrangement of new bone layers formed on the tension side along stretched fiber bundles after rotation. **C,** Same area after a retention period of 3 to 4 months. The bone and the principal fibers are rearranged much sooner than the displaced supra-alveolar structures.

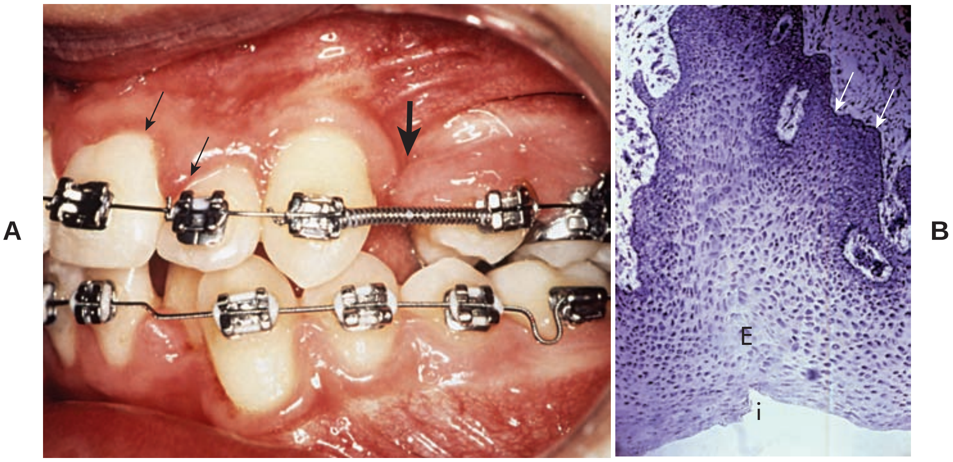

FIGURE 9-60 Fixed appliance for closure of an extraction space. **A,** With gingivitis of the incisors *(small arrows)* and invagination *(large arrow)* in the extraction area. **B,** Histologic appearance of the invagination *(i)* area. Deep proliferation of oral epithelium *(E)*. High levels of oxidative enzyme activity are present in the hyperplastic basal cell layers *(arrows)*. *(From Rönnerman A, Thilander B, Heyden G: Gingival tissue reactions to orthodontic closure of extraction sites: histologic and histochemical studies,* Am J Orthod *77:620, 1980.)*

increased amount of glykosaminoglycans[62] (Figure 9-60, *B*). Such "elastic" tissue together with the compression of the transseptal fibers may be responsible for relapse after closure of the extraction gap.

Changes during the Postretention Period

The length of the retention period to avoid relapse is controversial. Some recommend 2 to 5 years, whereas others have suggested a minimum of 10 years or longer. Analysis of not only orthodontically treated cases but also of nontreated cases in follow-up studies is of importance to learn more about post-retention development versus relapse.

A longitudinal study of individuals, not orthodontically treated, with well-shaped dental arches and normal occlusion ("ideal cases")[63,64] clearly showed the dentofacial changes from early childhood into adolescence, young adulthood, and late adulthood, changes that are a gradual process that has to be taken into consideration in orthodontic treatment. The circumference of the dental arches increased during eruption of the incisors and canines but thereafter continuously decreased, especially in the mandible (Figure 9-61). This will explain

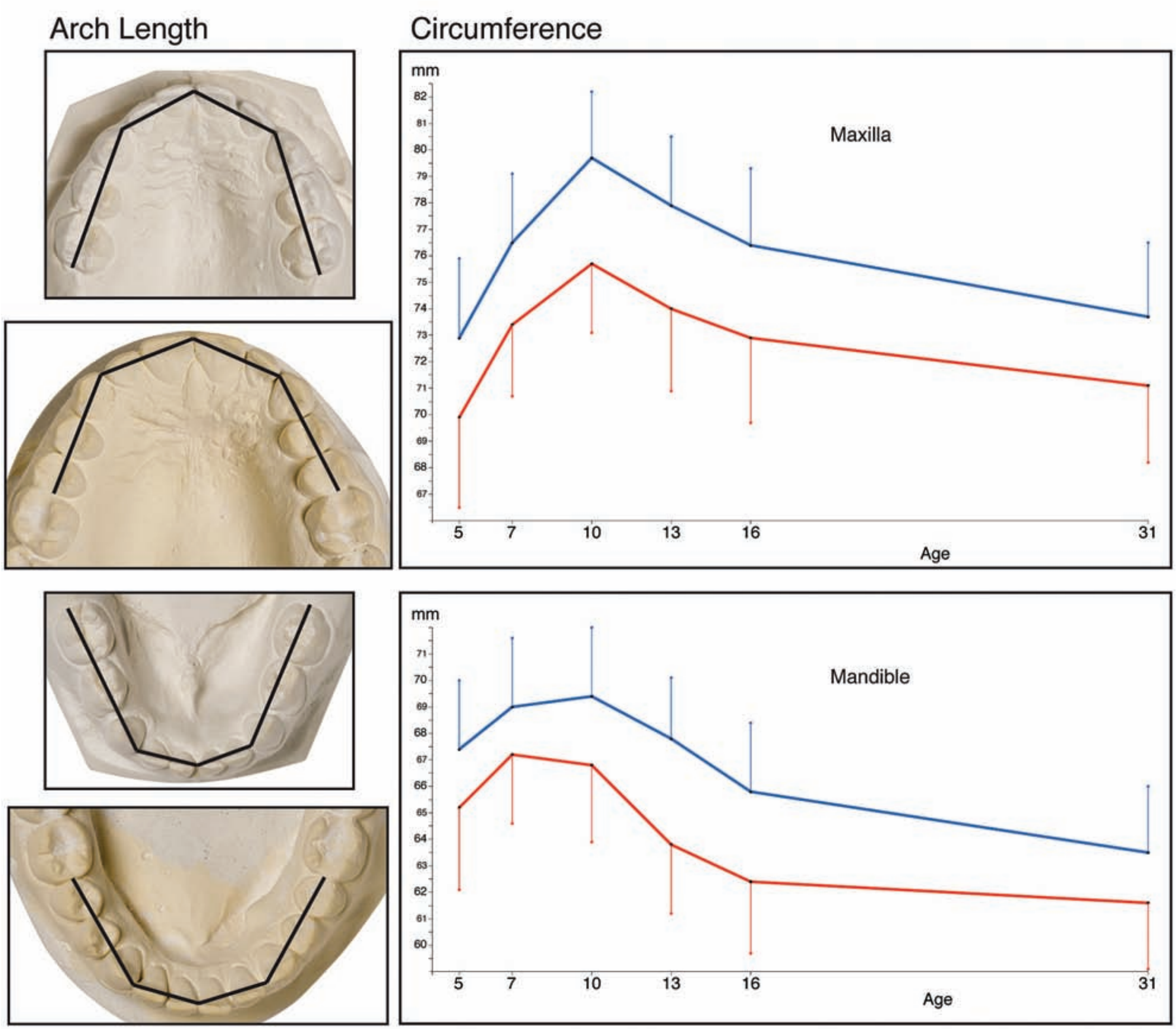

FIGURE 9-61 The dental arch circumference (mesial of the first permanent molars) in the maxilla and mandible in subjects with "ideal" occlusion. Females (red) and males (blue) followed from 5 to 31 years of age. Mean and standard deviation for each recording. *(From Thilander B: Dentoalveolar development in subjects with normal occlusion: A longitudinal study between the ages of 5 and 31 years,* Eur J Orthod *31:109, 2009.)*

why 12 of the 30 subjects, examined at 31 years of age, showed incisor crowding of different degree, even in cases with congenitally missing third molars (Figure 9-62). Width and depth of the dental arches also showed slow continuous changes of importance for postretention stability.

One interesting finding in that longitudinal study was the development of the palatal height. A continuous slow increase in this distance seems to indicate an important role in the tooth eruption mechanism (Figure 9-63). This knowledge is of importance in explaining the infraposition of an implant-supported crown as a continuous eruption of its adjacent teeth[65] (Figure 9-64).

The continuous dentoalveolar change, known as physiologic tooth migration, thus has to be distinguished from orthodontic relapse. The occlusion hence is to be regarded as a dynamic rather than as a static interrelation between facial structures.

SUMMARY

This chapter represents an update of the principal changes resulting from orthodontic forces acting on teeth and supporting structures, sutures, and the TMJ region. Unfavorable forces may initiate adverse tissue reactions. After orthodontic treatment, a rapid-to-slow relapse occurs during the period of remodeling of the periodontal structures. The tissue reactions in the gingiva differ from those in the periodontal ligament and are of different importance to maintain the stability of the tooth in its new position. Late changes occurring during the postretention period generally cannot be distinguished

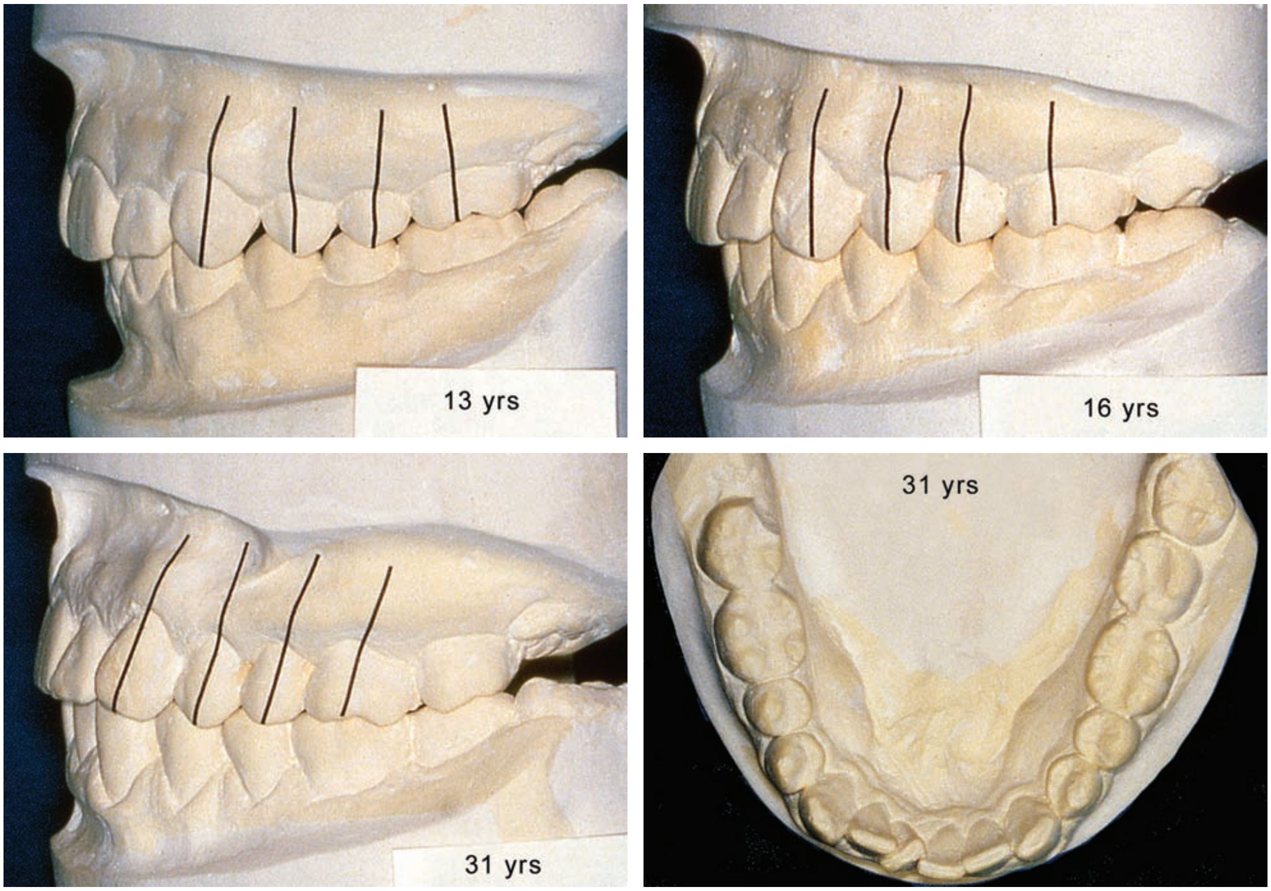

FIGURE 9-62 Study casts from a subject (male), classified as "normal" at 13 and 16 years, even at 31 years. Note the negative effect of physiological migration, resulting in 41 in a crowded position in spite of a congenital absence of 48 in contrast to fully erupted 38.

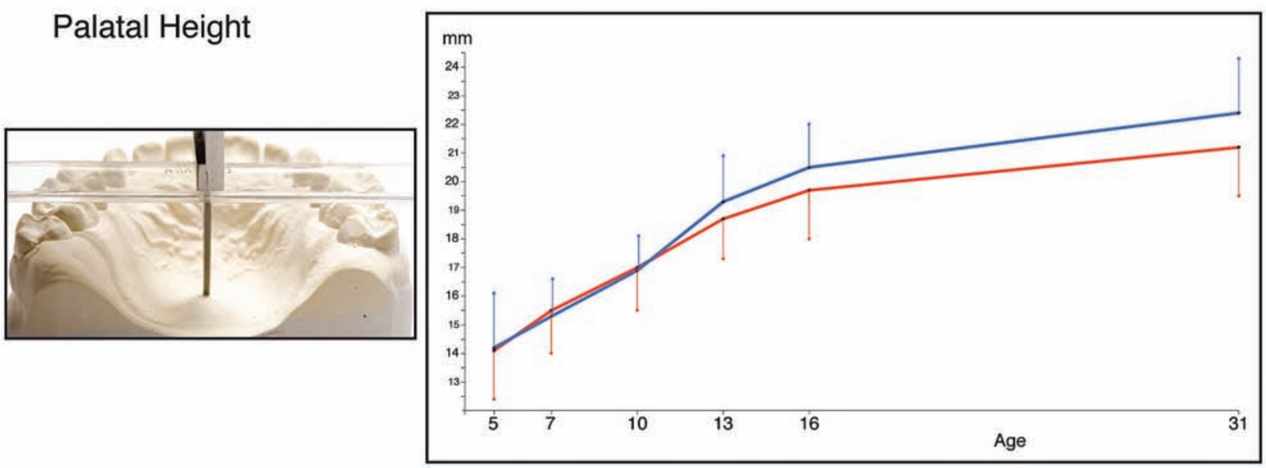

FIGURE 9-63 Palatal height (mm) in females (red) and males (blue), followed from 5 to 31 years of age; mean and standard deviation for each recording. *(From Thilander B: Dentoalveolar development in subjects with normal occlusion: A longitudinal study between the ages of 5 and 31 years,* Eur J Orthod *31:109, 2009.)*

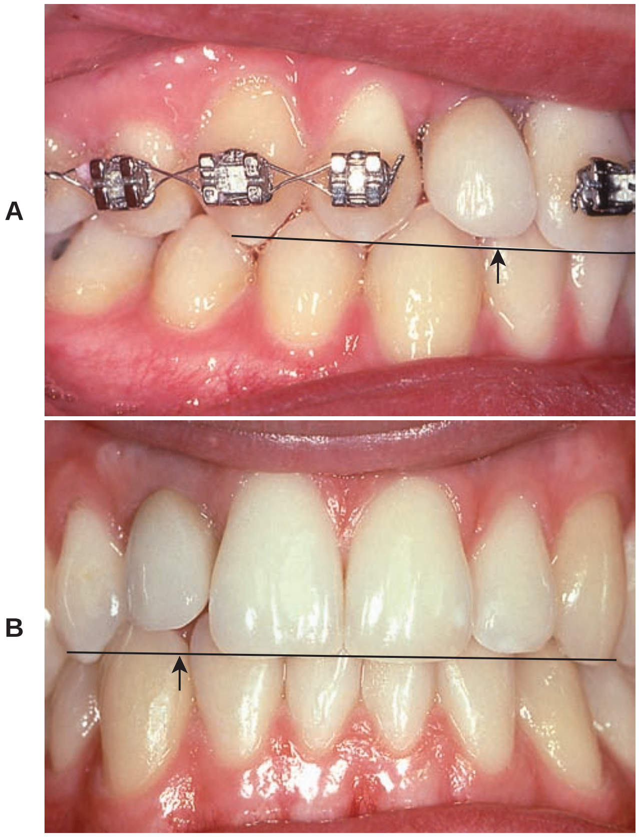

FIGURE 9-64 **A,** A patient with an implant-supported crown *(arrow)* replacing the congenitally missing upper right lateral incisor. **B,** Continuous eruption of the teeth adjacent to the implant from 16 to 24 years resulted in 1.6 mm of infraocclusion of the implant-supported crown *(arrow). (Adapted from Thilander B et al: Orthodontic aspects of the use of oral implants in adolescents: A 10-year follow-up study,* Eur J Orthod *23:715, 2001.)*

from normal aging processes that occur regardless of whether a person has been treated orthodontically. Even though the knowledge of tissue reaction in orthodontics is well documented by numerous experimental and clinical studies, many basic questions still are unanswered.

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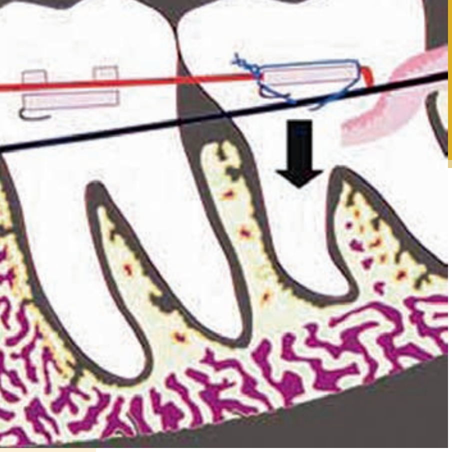

CHAPTER

10

Bone Physiology, Metabolism, and Biomechanics in Orthodontic Practice

W. Eugene Roberts

OUTLINE

- **Osteology**
  - Differential Osteology of the Maxilla and Mandible
  - Temporomandibular Articulation
- **Bone Physiology**
  - Specific Assessment Methodology
  - Classification of Bone Tissue
    - *Woven Bone*
    - *Lamellar Bone*
    - *Composite Bone*
    - *Bundle Bone*
- **Skeletal Adaptation: Modeling and Remodeling**
- **Cortical Bone Growth and Maturation**
  - Cutting and Filling Cones
    - *Structural and Metabolic Fractions*
- **Bone Metabolism**
- **Calcium Conservation**
  - Diet
  - Endocrinology
- **Skeletal Compromise**
- **Metabolic Bone Disease**
- **Biomechanics**
- **Sutures**
- **Distraction Osteogenesis**
- **Orthodontic Tooth Movement**
  - Occlusal Trauma and Root Resorption
  - Remodeling of Bones and Teeth
    - *Trabecular Bone Remodeling*
    - *Root Remodeling*
  - Induction of the Tooth Movement Response
- **Periodontal Ligament Response**
- **Osteoblast Histogenesis and Bone Formation**
- **Osteoclast Recruitment and Bone Resorption**
  - Intermittent versus Continuous Mechanics
  - Differential Anchorage
  - Rate of Tooth Movement
  - Periodontitis and Orthodontics
  - Endosseous Implants
    - *Retromolar Implant Anchorage*
    - *External Abutment Mechanism*
    - *Internal Abutment Mechanism*
    - *Mini-implants for Orthodontic Anchorage*
- **Summary**

The physiologic mediators of orthodontic therapy are the facial sutures, the temporomandibular joint (TMJ), alveolar bone, and the periodontal ligament (PDL). The PDL is the osteogenic bone–tooth interface; it is a modified periosteum with remarkable bone resorptive and formative capabilities. By means of the teeth, alveolar bone can be loaded in a noninvasive and relatively atraumatic manner. Clinical therapy is a combination of orthodontics (tooth movement) and orthopedics (relative repositioning of bones). The biomechanical response depends on the magnitude, direction, and frequency of applied load. Cell kinetic and multiple fluorochrome bone labeling studies have helped define the fundamental mechanisms of orthodontic and dentofacial orthopedic responses. This chapter explores the determinants of craniofacial bone morphology, mechanically mediated osteogenesis, and the physiologic mechanisms for therapeutic correction of malocclusion.

Bones have fascinated human beings since the dawn of time. Much of what is known about the evolution of vertebrates is based on the ordered recovery of bones and teeth from the soil. Over the millennia, these “relatively inert” structures tended to be well preserved. Compared with living bone, teeth are relatively inert structures. Accretion capability at the dentin–pulp interface (secondary dentin) is limited, and some turnover of the

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cementum occurs because of root resorption and cementum repair processes. However, bone is a dynamic structure that is adapting constantly to its environment. As a reservoir of calcium, bone remodeling (physiologic turnover) performs a critical life support role in mineral metabolism (Figure 10-1). In addition, the skeleton is the structural scaffold of the body. Collectively bones are essential elements for locomotion, antigravity support, and life-sustaining functions such as mastication. Mechanical adaptation of bone is the physiologic basis of orthodontics and dentofacial orthopedics. A detailed knowledge of the dynamic nature of bone physiology and biomechanics is essential for modern clinical practice.

OSTEOLOGY

In defining the physiologic basis of orthodontics, the initial consideration is the bone morphology (osteology) of the craniofacial complex. Through systematic study of a personal collection of more than 1000 human skulls, Spencer Atkinson provided the modern basis of craniofacial osseous morphology as it relates to the biomechanics of stomatognathic function. A frontal section of an adult skull shows the bilateral symmetry of bone morphology and functional loading (Figures 10-2 and 10-3). Because the human genome contains genes to pattern the structure of only half of the body, the contralateral side is a mirror image. Consequently, normal development of the head is symmetric; that is, unilateral structures are on the midline, and bilateral structures are equidistant from it. As shown in Figure 10-3, the vertical components of the cranium tend to be loaded in compression (negative stress), and the horizontal components are loaded in tension (positive stress). From an engineering perspective, the internal skeletal structure of the midface is similar to that of a ladder: vertical rails loaded in compression connected by rungs loaded in tension. This is one of the most efficient structures for achieving maximal compressive strength with minimal mass in a composite material.

Note in Figure 10-3 that there is no net tension across the palate in an adult. During the prenatal and early postnatal period, the palate grows in width via the posterior palatal synchondosis (primary growth center).[1] When the first deciduous molars establish a functional occlusion, the midpalatal suture evolves into a secondary growth site that responds to occlusal loading. A soft diet

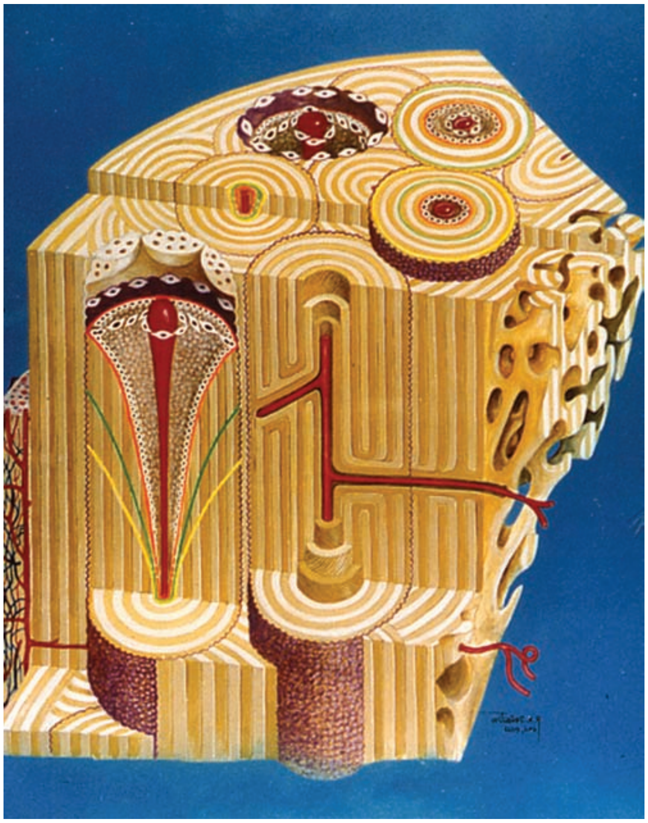


FIGURE 10-1 This artist's rendition of the dynamic principles of cortical bone remodeling was produced by the renowned dental illustrator Rolando De Castro. Remodeling is a vascularly mediated process of bone turnover that maintains the integrity of structural support and is a source of metabolic calcium. Osteoblasts are derived from preosteoblasts circulating in the blood, and perivascular mesenchymal cells give rise to osteoblasts. Note the three colored chevrons (*yellow, green*, and *orange*) progressively marking the mineralization front of the evolving second osteon that is moving superiorly on the left. *[From Roberts WE, Arbuckle GR, Simmons KE: What are the risk factors of osteoporosis? Assessing bone health,* J Am Dent Assoc *122(2):59-61, 1991.]*

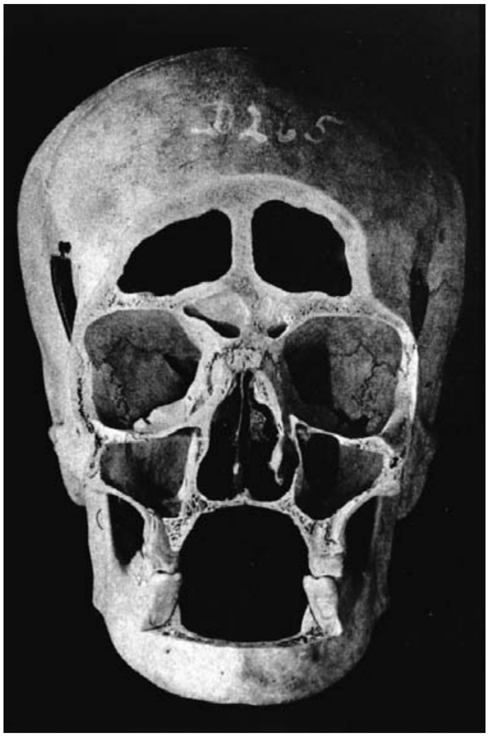


FIGURE 10-2 Frontal section of a human skull in the plane of the first molars. *(From Atkinson SR: Balance: the magic word,* Am J Orthod *50:189, 1964.)*

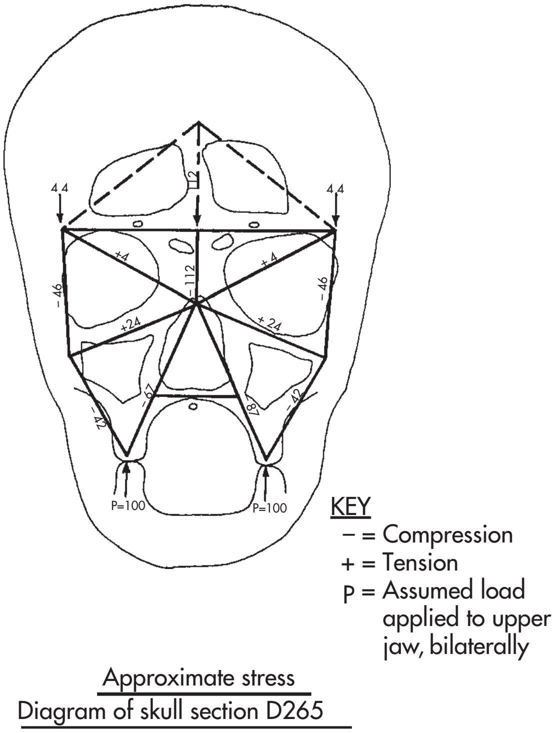


FIGURE 10-3 Two-dimensional vector analysis of stress in the frontal section of the human skull depicted in Figure 10-2. Relative to a bilateral biting force of 100 arbitrary units, the load is distributed to the vertical components of the midface as compressive (negative) stress. The horizontal structural components are loaded in tension. In a nongrowing individual the stress across the midpalatal suture is 0. When masticating, loads increase and the midpalatal suture is subjected to a tensile load, resulting in an increase in maxillary width. *(From Atkinson SR: Balance: the magic word,* Am J Orthod *50:189, 1964.)*

decreases the rate of palatal expansion during the growing years.[2] Because growth in width of the maxilla reflects the magnitude of occlusal function,[3] inadequate functional loading may result in functional aberrations such as posterior crossbite.

Differential Osteology of the Maxilla and Mandible

Although equal and opposite functional loads are delivered to the maxilla and mandible, the maxilla transfers stress to the entire cranium, whereas the mandible must absorb the entire load. Consequently, the mandible is much stronger and stiffer than the maxilla. A midsagittal section through the incisors (Figure 10-4) and a frontal section through the molar region (Figure 10-5) show the distinct differences in the osseous morphology of the maxilla and mandible. The maxilla has relatively thin cortices that are interconnected by a network of trabeculae (see Figures 10-2, 10-4, and 10-5). Because it is loaded primarily in compression, the maxilla is structurally similar to the body of a vertebra.

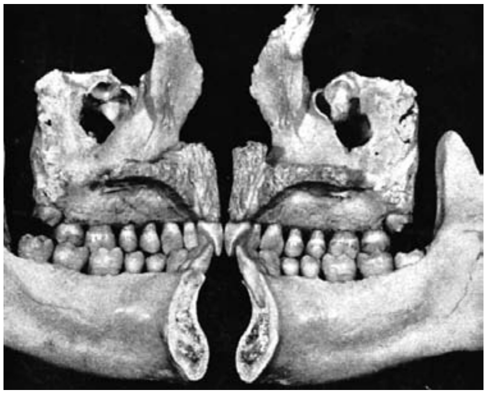


FIGURE 10-4 Midsagittal section of a human skull shows that the maxilla is composed primarily of trabecular (spongy) bone. The opposing mandible has thick cortices connected by relatively coarse trabeculae. *(From Atkinson SR, Balance: the magic word,* Am J Orthod *50:189, 1964.)*

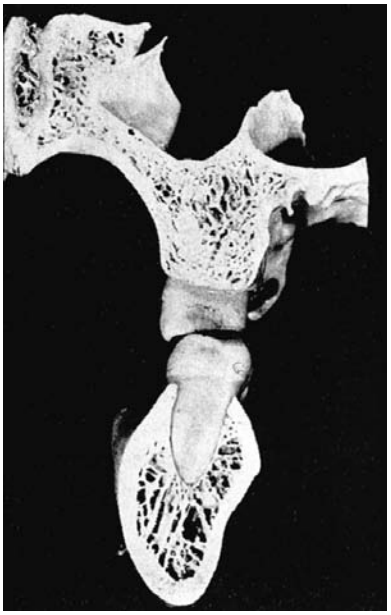


FIGURE 10-5 Frontal section of the maxilla and mandible in the plane of the first molars. Because it transmits masticatory loads to the entire cranium, the maxilla has thin cortices connected by relatively fine trabeculae. The mandible, however, is loaded in bending and torsion; it therefore is composed of thick cortical bone connected by coarse, oriented trabeculae. *(From Atkinson SR: Balance: the magic word,* Am J Orthod *50:189, 1964.)*

The mandible, however, has thick cortices and more radially oriented trabeculae (see Figures 10-4 and 10-5). The structural array is similar to the shaft of a long bone and indicates that the mandible is loaded predominantly in bending and torsion. This biomechanical impression based on osteology is confirmed by in vivo strain-gauge studies in monkeys. Hylander[4,5] demonstrated substantial bending and torsion in the body of the mandible associated with normal masticatory function (Figure 10-6). A clinical correlation consistent with this pattern of surface strain is the tendency of some human beings

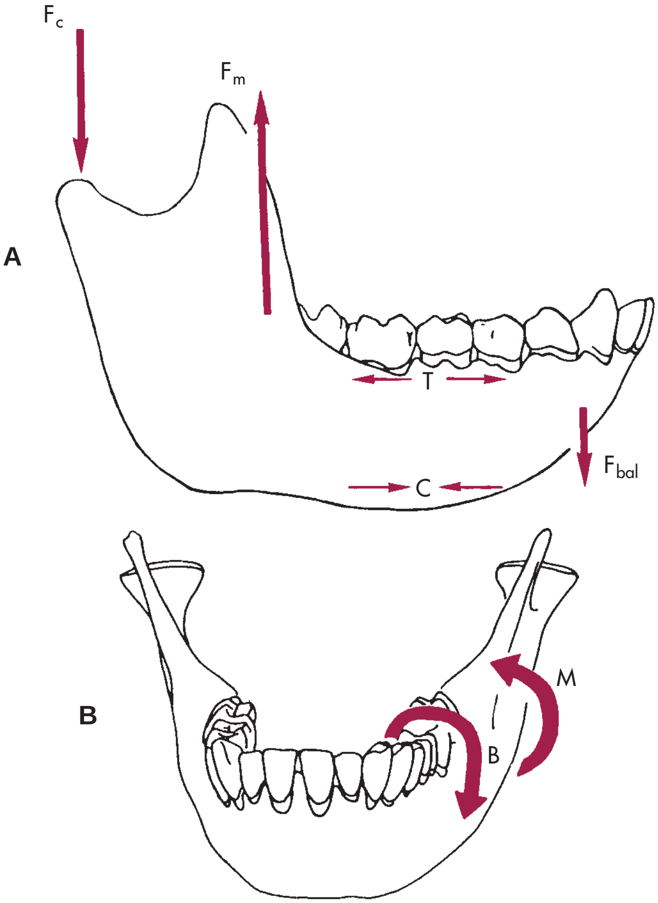


FIGURE 10-6 Stress patterns in the primate mandible during unilateral mastication. F_c and F_m are the condylar reaction and the resultant muscle forces on the balancing side, respectively. F_{bal} is the force transmitted through the symphysis from the balancing to the working side. *T* and *C* indicate the location of tensile stress and compressive stress, respectively. **A,** During the power stroke, the mandibular corpus on the balancing side is bent primarily in the sagittal plane, resulting in tensile stress along the alveolar process and compressive stress along the lower border of the mandible. **B,** On the working side, the corpus is twisted primarily about its long axis (it also experiences direct shear and is slightly bent). The muscle force on this side tends to evert the lower border of the mandible and invert the alveolar process (*curved arrow M*). The twisting movement associated with the bite force has the opposite effect (*curved arrow B*). The portion of the corpus between these two twisting movements experiences maximal twisting stress. *(From Hylander WL: Patterns of stress and strain in the macaque mandible. In Carlson DS, editor:* Craniofacial biology, *Ann Arbor, MI, 1981, Center for Human Growth and Development.)*

to form tori in the areas of maximal bending and torsion (Figure 10-7). The largest tori are on the side on which the individual habitually chews (preferential working side).

Temporomandibular Articulation

The TMJ is the principal adaptive center for determining the intermaxillary relationship in all three planes of space. Figure 10-8 shows optimal skeletal development consistent with normal morphology of the TMJ.

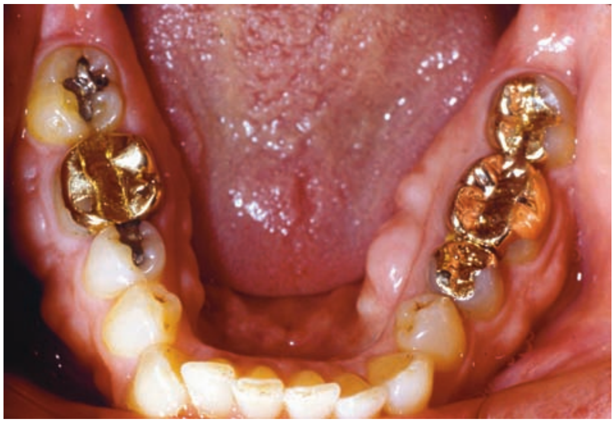


FIGURE 10-7 Occlusal view of the mandibular dentition of a male patient with extensive buccal and lingual tori. Note that the exostoses are most extensive in the area of the second premolar and first molar, the area of maximal torsion in the posterior segment of the mandible.

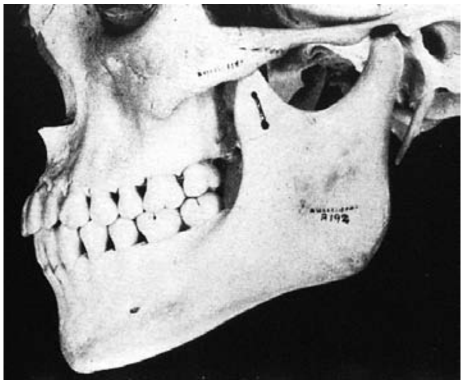


FIGURE 10-8 Adult human skull with ideal occlusion and osseous form of the maxilla and mandible. Note the ideal anatomic form of the condyle and articular fossa of the temporomandibular joint. *(From Atkinson SR: Balance: the magic word,* Am J Orthod *50:189, 1964.)*

Biomechanics studies have demonstrated that the TMJ eminence develops a shape that minimizes joint loads.[6] Figure 10-9 shows aberrant skeletal and dental relationships consistent with degeneration of the fossa and mandibular condyle (i.e, the enlarged mushroom shape of the condylar process, the roughened topography of the articulating surfaces, and the loss of articular cartilage and subchondral plate). Progressive degeneration or hyperplasia of one or both mandibular condyles may result in substantial intermaxillary discrepancies in the sagittal, vertical, and frontal dimensions. The growth and development of the TMJ in response to facial growth are well known. During childhood and adolescence, the face grows several centimeters anteriorly and inferiorly. Adaptation of the TMJ allows this substantial change to occur without disturbing the intermaxillary relationship of the dentition (e.g., Class I occlusion remains Class I). In the adult years, the intermaxillary relationship continues to change but at a slower rate. The face lengthens

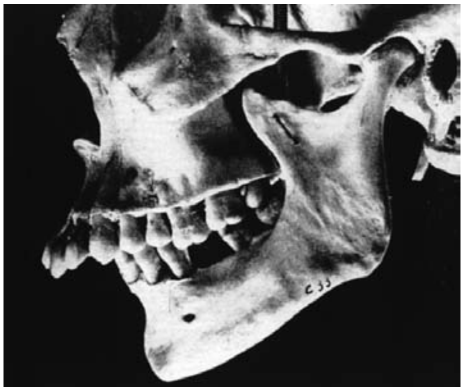


FIGURE 10-9 Adult human skull with a severe Class II malocclusion. Note the degeneration of the temporomandibular joint (i.e., the large, mushroom-shaped condyle and the enlarged, roughened articular fossa). *(From Atkinson SR: Balance: the magic word,* Am J Orthod *50:189, 1964.)*

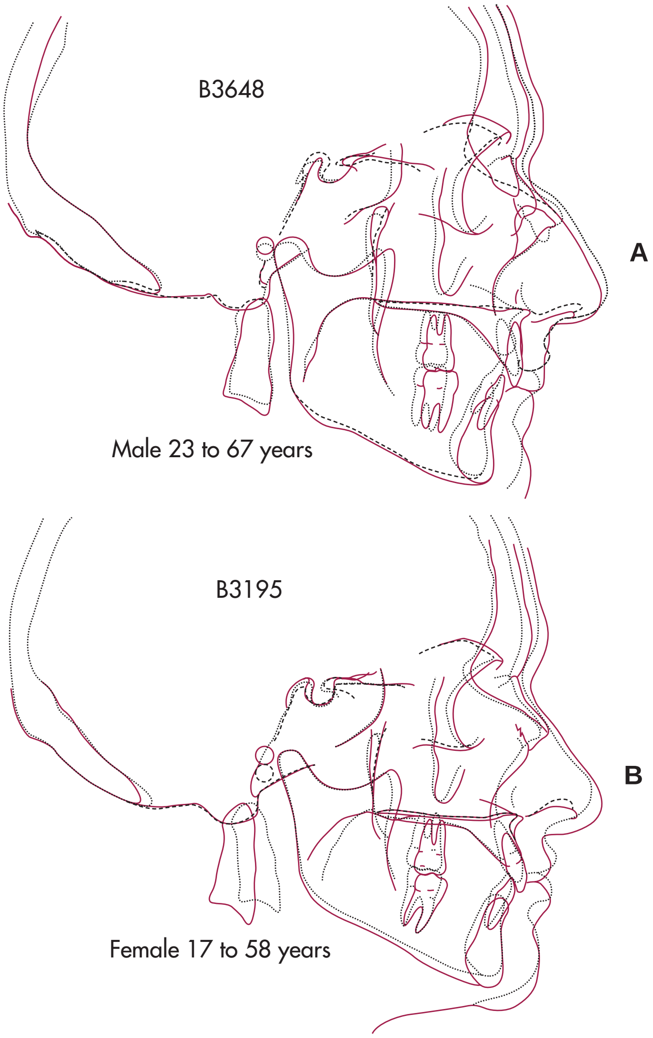


FIGURE 10-10 **A,** Superimposed cephalometric tracings of a male patient at ages 23 and 67 years (*black* and *red* tracings, respectively). Note the downward and forward growth of the mandible and the substantial increase in the length of the face. The nasal form was altered by a rhinoplasty in the intervening years. **B,** Superimposed cephalometric tracings of an adult female at ages 17 and 58 years (*black* and *red* tracings, respectively). Note the downward growth of the mandible and the substantial increase in the length of the face. *(From Behrents RG: Adult facial growth. In Enlow DH, editor:* Facial growth*, ed 3, Philadelphia, 1990, WB Saunders.)*

and may rotate anteriorly as much as 10 mm over the adult lifetime.[7] The mandible adapts to this change by lengthening and maintaining the intermaxillary dental relationship (Figure 10-10). However, if the TMJs of an adult undergo bilateral degenerative change, whether or not symptomatic, the mandible can decrease in length, resulting in a shorter, more convex face (Figure 10-11). Cone-beam computed tomography (CBCT) has revealed intraosseous changes in the metaphysis of a degenerating mandibular condyle (Figure 10-12). Compared with the normal left side, there are trabecular sclerosis and subcondylar osteolytic lesions on the degenerating side. The picture is consistent with a mechanical overload of the TMJ. Animal studies have described the molecular mechanism of TMJ degeneration due to mechanical overload: (1) expression of vascular endothelial growth factor (VEGF), (2) hypoxia-inducible factor-1α (Hif-1α) is activated, and (3) osteoclastogenesis via repression of osteoprotegerin (Opg) expression results in osteolytic lesions.[8]

Within physiologic limits, the TMJ has remarkable regenerative and adaptive capabilities. The TMJ can recover spontaneously from degenerative episodes (Figure 10-13). However, more advanced degeneration associated with abnormal occlsual loading requires distraction of the degenerating condyle with a removable orthotic, orthodontic alignment, and occlusal reconstuction to create a balance occlusal load bilaterally (Figures 10-14 and 10-15). Unlike other joints in the body, the TMJ has a remarkable ability to adapt to altered jaw structure and function. After a subcondylar fracture, the condylar head is pulled medially by the superior pterygoid muscle and resorbs. If the interocclusal relationship is maintained, a new condyle forms and assumes normal function. Unilateral subcondylar fractures usually result in regeneration of a new functional condyle with no significant deviation of the mandible.[9] However, about one fourth of subcondylar fractures result in a mandibular deviation toward the injured side, resulting in an asymmetric Class II malocclusion with a midline deviation.

Another sequela of mandibular trauma is internal derangement such as a unilateral closed lock (a condyle distally displaced relative to the disc). If the range of motion is reduced in a growing patient, the compromised function may inhibit mandibular growth, resulting in a cant of the occlusal plane. Progressive dysfunction and pain may ensue, particularly when associated with occlusal trauma. Reestablishing normal bilateral function allows the compromised condyle or condyles to adapt favorably.

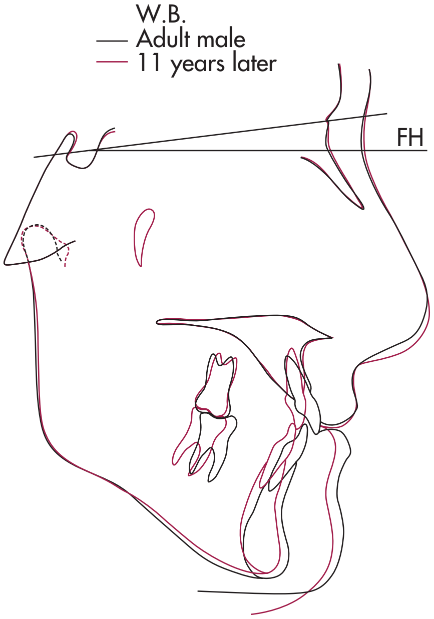


FIGURE 10-11 Superimposed cephalometric tracings of a middle-aged man over an 11-year period. Although the soft tissue changes are similar to those seen in other adult males (see Figure 10-10, *B*), the less prominent mandible and more convex skeletal profile are consistent with a shortened mandible. This man had a history of bilateral temporomandibular internal derangement that progressed to crepitus. However, despite the substantial change in facial form and occlusal compensation, no appreciable pain was reported.

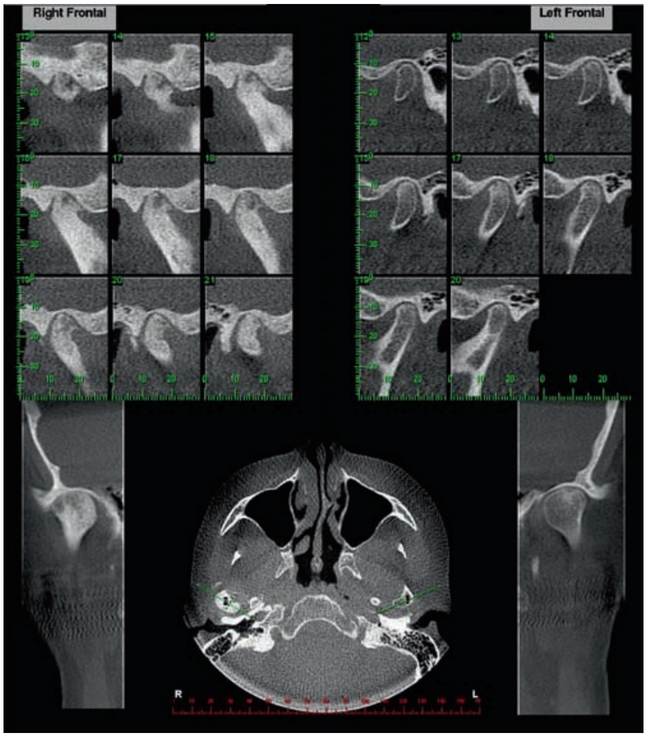


FIGURE 10-12 A CBCT image reveals osseous degeneration of the right mandibular condyle in a 65-year-old female. In both the frontal and sagittal cuts, note the lack of joint space between the condyle and the fossa, as well as the subcortical plate radiolucent erosions in the trabecular bone of the condylar metaphysis.

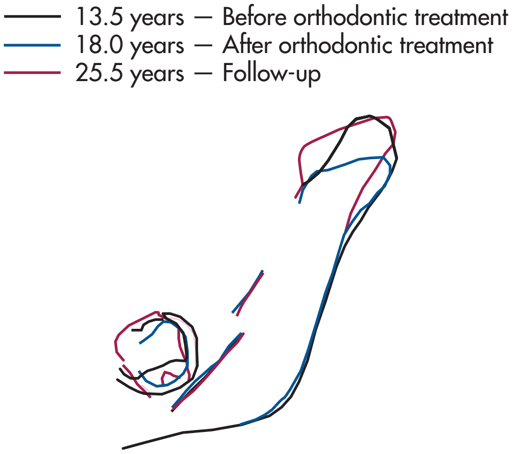

13.5 years — Before orthodontic treatment
18.0 years — After orthodontic treatment
25.5 years — Follow-up

FIGURE 10-13 Superimposed tracings of a series of panoramic radiographs documenting the degeneration of a mandibular condyle between 13.5 and 18 years of age. Between the ages of 18 and 25.5 years, the degenerative condyle grew, restoring the original length of the mandible. *[From Peltola JS, Kononen M, Nystrom M: A follow-up study of radiographic findings in the mandibular condyles of orthodontically treated patients and associations with TMD,* J Dent Res *74(9):1571, 1995.]*

BONE PHYSIOLOGY

The morphology of bone has been well described, but its physiology is elusive because of the technical limitations inherent in the study of mineralized tissues. Accurate assessment of the orthodontic or orthopedic response to applied loads requires time markers (bone labels) and physiologic indexes (DNA labels, histochemistry, and in situ hybridization) of bone cell function. Systematic investigation with these advanced methods has defined new concepts of clinically relevant bone physiology.

Specific Assessment Methodology

Physiologic interpretation of the response to applied loads requires the use of specially adapted methods:

- Mineralized sections are an effective means of accurately preserving structure and function relationships.[10]
- Polarized light birefringence detects the preferential orientation of collagen fibers in the bone matrix.[11]
- Fluorescent labels (e.g., tetracycline) permanently mark all sites of bone mineralization at a specific point in time (anabolic markers).[11]
- Microradiography assesses mineral density patterns in the same sections.[12]
- Autoradiography detects radioactively tagged precursors (e.g., nucleotides and amino acids) used to mark physiologic activity.[13–15]
- Nuclear volume morphometry differentially assesses osteoblast precursors in a variety of osteogenic tissues.[16]

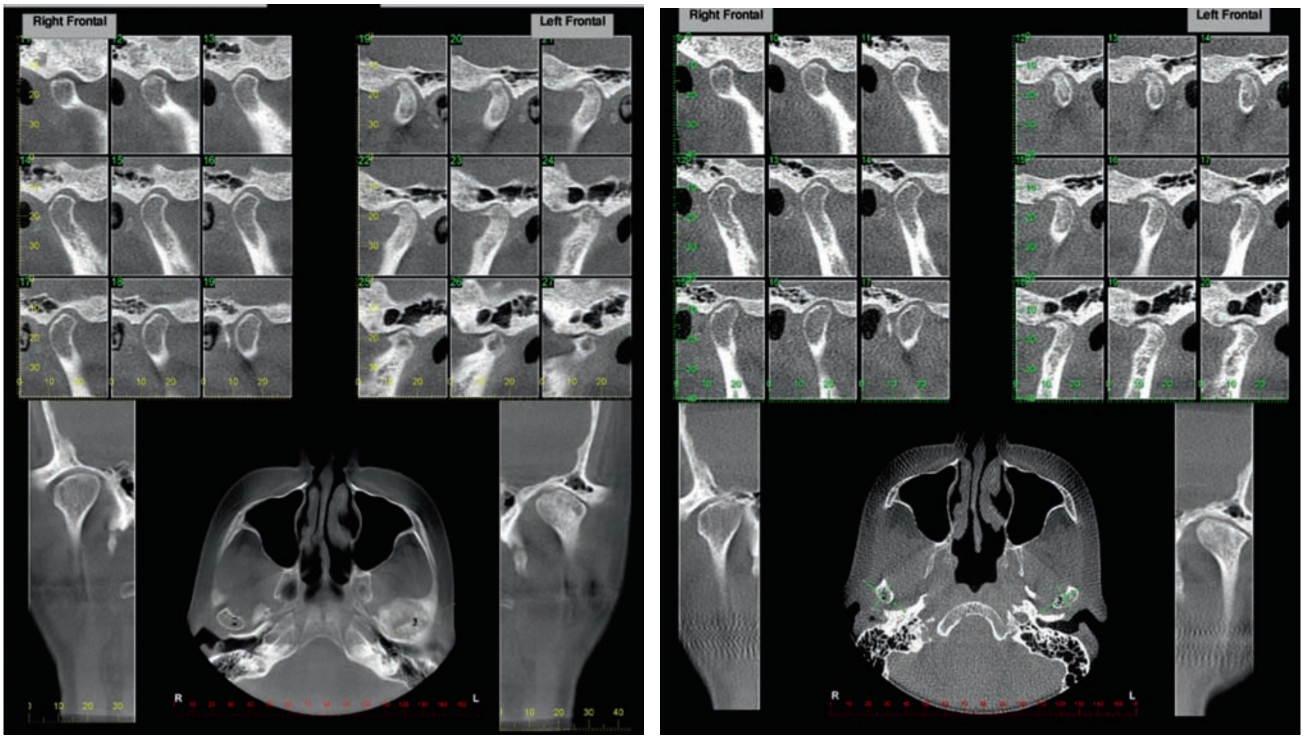
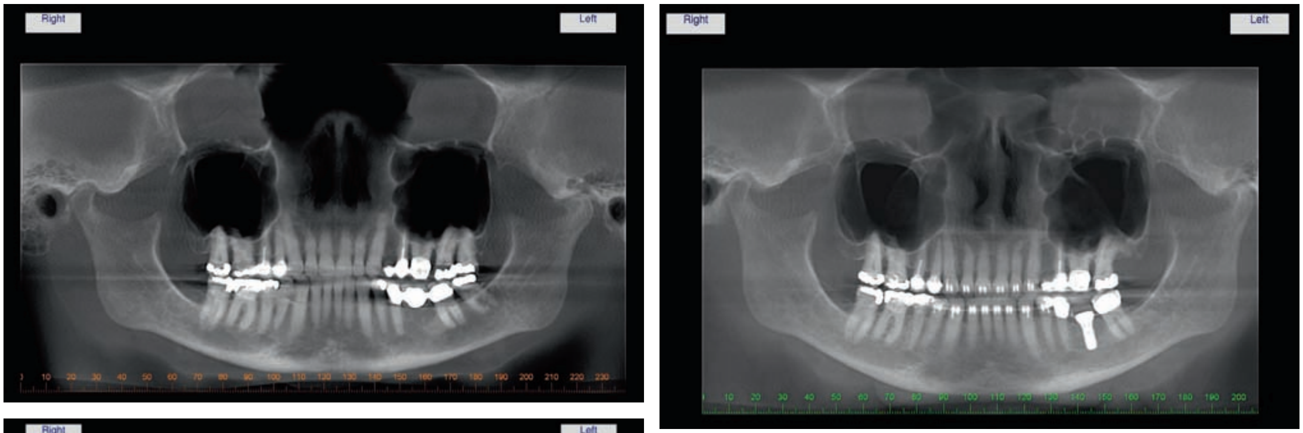


FIGURE 10-14 Pretreatment CBCT imaging of a 72-year-old female shows osseous degeneration of the left mandidular condyle, characterized by subcortical radiolucent lesions that are noted in both the frontal and sagittal cuts. A well-defined osteophyte is noted on the anterior surface of the left mandibular condyle.



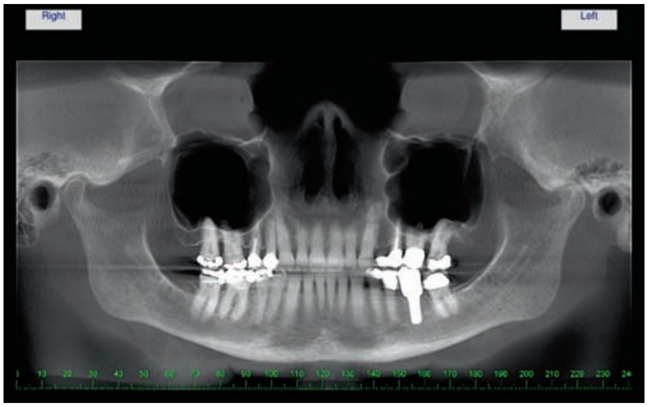


FIGURE 10-15 A posttreatment CBCT scan was performed on the patient imaged in Figure 10-14. Condylar distraction of the left mandibular condyle, producing a left posterior open bite of about 2 mm, resulted in resolution of the subcortical osteolytic lesions, but the osteophyte on the anterior surface persisted. The patient subsequently received coordinated orthodontics and restorative treatment to correct the posterior openbite by increasing the vertical dimension of occlusion.

CASE STUDY 10-1 TEMPOROMANDIBULAR DISCREPANCIES

W. Eugene Roberts

A 52-year-old man sought treatment for a long history of facial pain, occlusal dysfunction, and an internal derangement of the right mandibular condyle (Figures 10-16 and 10-17). Intracapsular surgery was performed on the right TMJ to repair the internal derangement. After transient postoperative improvement, degeneration of the TMJ accelerated, the pain increased, and a progressive anterior open bite malocclusion developed. Masticatory function deteriorated, and an internal derangement of the left TMJ was noted. Bilateral intracapsular surgery was performed to restore "normal jaw function." After the second surgical procedure the patient suffered for 10 years with chronic pain and progressive bilateral degeneration of both TMJs. Orthodontic and orthotic (splint) therapy failed to relieve the pain and functional debilitation. The patient declined further treatment and is being managed with pain medication. From a physiologic perspective, intracapsular surgery usually is contraindicated because it inhibits the natural ability of the joint to adapt to changing biomechanical demands. The TMJ is a remarkably regenerative and adaptive joint if its physiologic limits are respected.

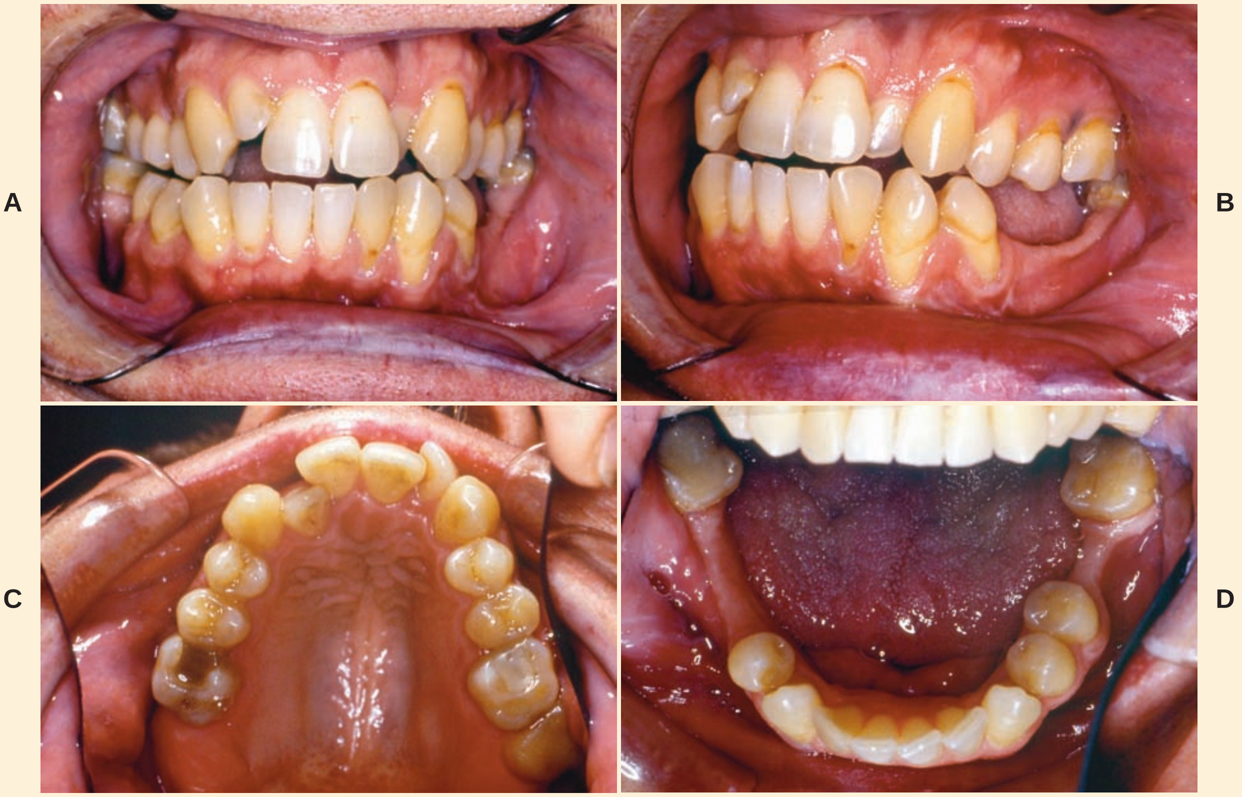


FIGURE 10-16 Frontal view **(A),** lateral view **(B),** maxillary occlusal view **(C),** and mandibular occlusal view **(D)** of the dentition of a 52-year-old man with a partly edentulous open bite malocclusion. Note the atrophic extraction sites and gingival recession. *[From Roberts WE, et al: Adjunctive orthodontic therapy in adults over 50 years of age,* J Ind Dent Assoc *76(2):33, 1997.]*

- Cell kinetics is a quantitative analysis of cell physiology based on morphologically distinguishable events in the cell cycle (i.e., DNA synthesis [S] phase, mitosis, and differentiation-specific change in nuclear volume).[16,17]
- Finite element modeling is an engineering method of calculating stresses and strains in all materials, including living tissue.[18–21]
- Microelectrodes inserted in living tissue such as the PDL can detect electrical potential changes associated with mechanical loading.[17,22]
- Backscatter emission is a variation of electron microscopy that assesses relative mineral density at the microscopic level in a block specimen.[23]
- Microcomputed tomography is an in vitro imaging method for determining the relative mineral density of osseous tissue down to a resolution of about 5 mm (about the size of an osteoblast nucleus).[24]
- Microindentation testing is a method for determining the mechanical properties of bone at the microscopic level.[25]

CASE STUDY 10-1 **TEMPOROMANDIBULAR DISCREPANCIES—cont'd**

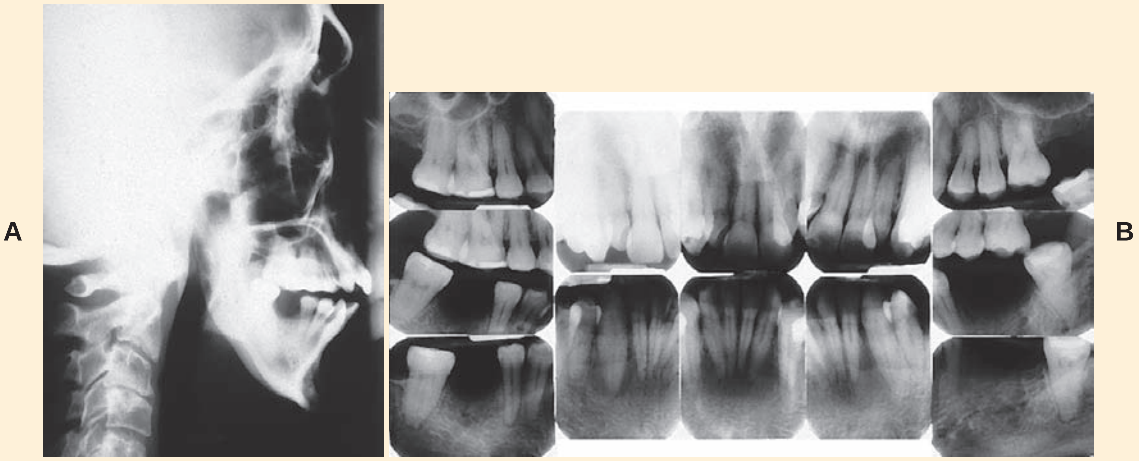


FIGURE 10-17 **A,** Cephalometric radiograph of the patient shown in Figure 10-16 shows a skeletal open bite with a steep mandibular plane and a relatively short ramus. The thin symphyseal cortex is consistent with a systemic osteopenia. **B,** A full-mouth radiographic survey shows a generalized lack of cortical bone at the alveolar crest and a pattern of indistinct lamina dura and trabeculae. This generalized ground-glass appearance of the alveolar bone is consistent with high-turnover metabolic bone disease. *[From Roberts WE, et al: Adjunctive orthodontic therapy in adults over 50 years of age,* J Ind Dent Assoc *76(2):33, 1997.]*

For a detailed discussion and illustration of the methods used to investigate the inherent bone physiologic mechanisms of bone, refer to the previous edition of this text and to two issues of *Seminars in Orthodontics* (June 2004 and December 2006). The first issue focuses on bone development and its inherent modeling mechanism, applied to tooth movement and dentoalveolar adaptation. The second issue is an advanced discussion of the bone remodeling mechanism, osteogenesis imperfecta, retromolar implant anchorage, and the use of stainless steel mini-screws in the zygomatic crest.

Classification of Bone Tissue

Orthodontic tooth movement results in rapid formation of relatively immature new bone (Figure 10-18). During the retention period, the newly formed bone remodels and matures. To appreciate the biological mechanism of orthodontic therapy, the practitioner must have a knowledge of bone types.

Woven Bone. Woven bone varies considerably in structure; it is weak, disorganized, and poorly mineralized. Woven bone serves a crucial role in wound healing by (1) rapidly filling osseous defects, (2) providing initial continuity for fractures and osteotomy segments, and (3) strengthening a bone weakened by surgery or trauma. The first bone formed in response to orthodontic loading usually is the woven type. Woven bone is not found in the adult skeleton under normal, steady-state conditions; rather, it is compacted to form composite bone, remodeled to lamellar bone, or rapidly resorbed if prematurely loaded.[12,26] The functional limitations of woven bone are an important aspect of orthodontic retention (Figure 10-19) and of the healing period following orthognathic surgery.[27]

Lamellar Bone. Lamellar bone, a strong, highly organized, well-mineralized tissue, makes up more than 99% of the adult human skeleton. When new lamellar bone is formed, a portion of the mineral component (hydroxylapatite) is deposited by osteoblasts during primary mineralization (Figure 10-20, *D*). Secondary mineralization, which completes the mineral component, is a physical process (crystal growth) that requires many months. Within physiologic limits the strength of bone is related directly to its mineral content.[28,29] The relative strengths of different histologic types of osseous tissue can be stated thus: woven bone is weaker than new lamellar bone, which is weaker than mature lamellar bone.[27] Adult human bone is almost entirely of the remodeled variety: secondary osteons and spongiosa.[11,29,30] The full strength of lamellar bone that supports an orthodontically moved tooth is not achieved until about 1 year after completion of active treatment. This is an important consideration in planning orthodontic retention (Figure 10-21) and in the postoperative maturation period that follows orthognathic surgery.

Composite Bone. Composite bone is an osseous tissue formed by the deposition of lamellar bone within a woven bone lattice, a process called *cancellous compaction*.[10,31] This process is the quickest means of producing relatively strong bone.[32] Composite bone is an important intermediary type of bone in the physiologic response to

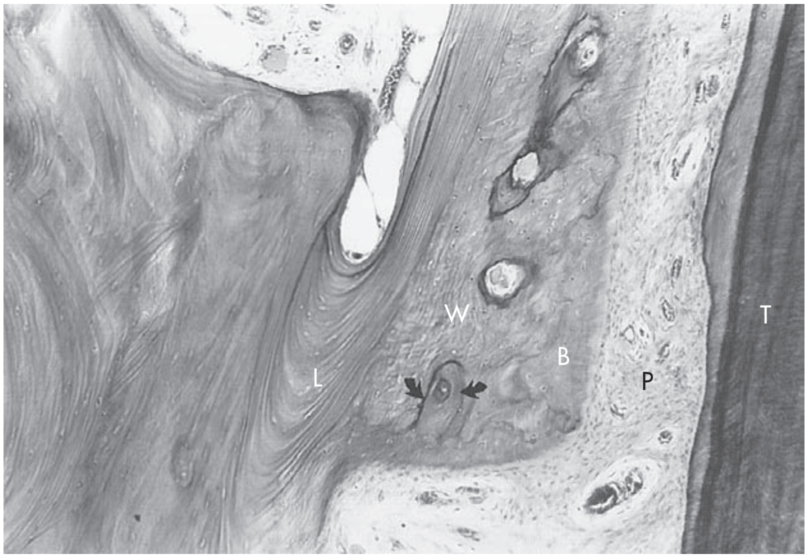


FIGURE 10-18 A section of human periodontium from the lower first molar region shows a typical histologic response to orthodontic tooth movement. With respect to the mature lamellar bone (*L*) on the left, the tooth (*T*) is being moved to the right. The first bone formed adjacent to the periodontal ligament (*P*) is of the woven type (*W*). Subsequent lamellar compaction forms primary osteons of composite bone (*arrows*). Bundle bone (*B*) is formed where ligaments such as the periodontal ligament are attached. *[From Roberts WE, et al: Implants: Bone physiology and metabolism,* Calif Dent Assoc J *15(10):58, 1987.]*

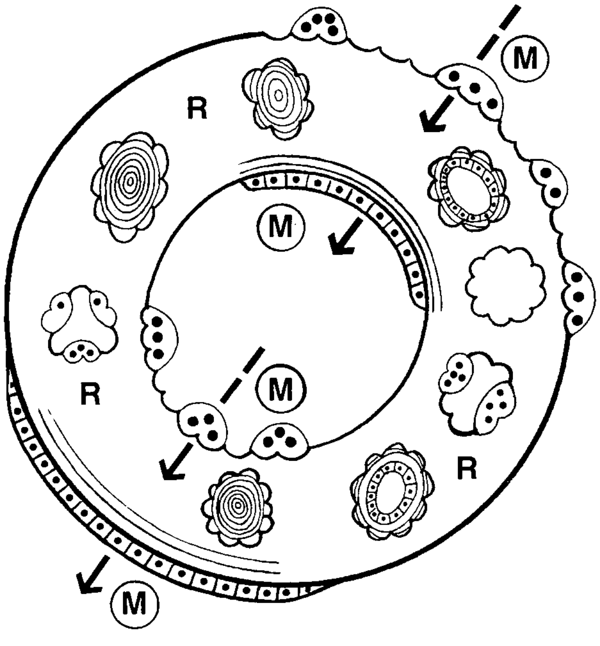


FIGURE 10-19 A schematic cross section of cortical bone shows surface modeling (*M*), which is the process of uncoupled resorption and formation. Remodeling (*R*) is the turnover of existing bone. *(From Roberts WE, et al: Remodeling of devitalized bone threatens periosteal margin integrity of endosseous titanium implants,* Ind Dent Assoc J *68:19, 1989.)*

orthodontic loading (see Figure 10-18), and it usually is the predominant osseous tissue for stabilization during the early process of retention or postoperative healing. When the bone is formed in the fine compaction configuration, the resulting composite of woven and lamellar bone forms structures known as *primary osteons*. Although composite bone may be high-quality, load-bearing osseous tissue, it eventually is remodeled into secondary osteons.[11,27]

Bundle Bone. Bundle bone is a functional adaptation of lamellar structure to allow attachment of tendons and ligaments. Perpendicular striations, called Sharpey fibers, are the major distinguishing characteristics of bundle bone. Distinct layers of bundle bone usually are seen adjacent to the PDL (see Figure 10-18) along physiologic bone-forming surfaces.[33] Bundle bone is the mechanism of ligament and tendon attachment throughout the body.

SKELETAL ADAPTATION: MODELING AND REMODELING

Skeletal adaptation to the mechanical environment is achieved through changes in (1) bone mass, (2) geometric distribution, (3) matrix organization, and (4) collagen orientation of the lamellae. In addition to these adaptive mechanisms that influence bone formation, the mechanical properties of osseous structures change as a result of maturation, function, aging, and pathologic processes. A few physiologic and pathologic examples are (1) secondary mineralization, (2) mean bone age, (3) fatigue damage, and (4) loss of vitality (pathologic hypermineralization).[33]

Trabecular and cortical bone grow, adapt, and turn over by means of two fundamentally distinct mechanisms: modeling and remodeling. In bone modeling, independent sites of resorption and formation change the form (shape or size or both) of a bone. In bone

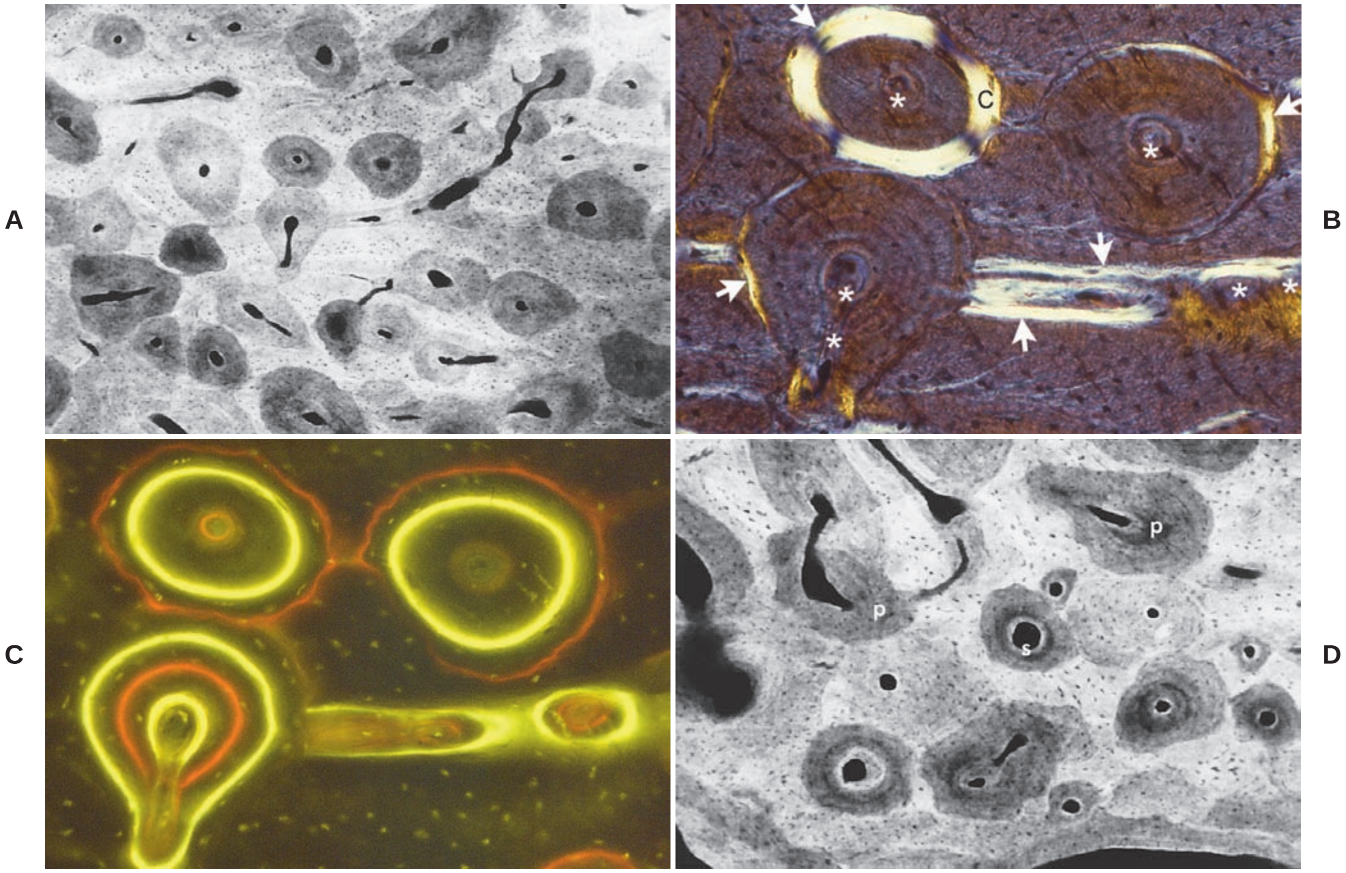


FIGURE 10-20 **A,** Microradiograph provides a physiologic index of bone turnover and relative stiffness. The more radiolucent (*dark*) osteons are the youngest, the least mineralized, and the most compliant. Radiodense (*white*) areas are the oldest, most mineralized, and rigid portions of the bone. **B,** Polarized light microscopy shows the collagen fiber orientation in bone matrix. Lamellae with a longitudinally oriented matrix (*C*) are particularly strong in tension, whereas a horizontally oriented matrix (dark) has preferential strength in compression (*arrows* mark resorption arrest lines, and *asterisks* mark vascular channels). **C,** Multiple fluorochrome labels administered at 2-week intervals demonstrate the incidence and rates of bone formation. **D,** This microradiograph shows an array of concentric secondary osteons (haversian systems) characteristic of rapidly remodeling cortical bone. Primary (*p*) and beginning secondary (*s*) mineralization are more radiolucent and radiodense, respectively. *(From Roberts WE, et al:* Bone biodynamics in orthodontic and orthopedic treatment: craniofacial growth series, *vol 27, Ann Arbor, 1991, University of Michigan Press.)*

remodeling, a specific, coupled sequence of resorption and formation occurs to replace previously existing bone (see Figure 10-19). The mechanism for internal remodeling (turnover) of dense compact bone involves axially oriented cutting and filling cones (Figure 10-22).[10] From an orthodontic perspective, the biomechanical response to tooth movement involves an integrated array of bone modeling and remodeling events (Figure 10-23, *A*). Bone modeling is the dominant process of facial growth and adaptation to applied loads such as headgear, rapid palatal expansion, and functional appliances. Modeling changes can be seen on cephalometric tracings (Figure 10-23, *B*), but remodeling events, which usually occur at the same time, are apparent only at the tissue level. True remodeling usually is not imaged on clinical radiographs.[34] For a detailed discussion of the modeling mechanisms of tooth movement and alveolar bone adaptation, refer to Roberts et al.[35] The remodeling (bone turnover) aspect of tooth movement is reviewed in Roberts et al.[35] Constant remodeling (internal turnover) mobilizes and redeposits calcium by means of coupled resorption and formation: bone is resorbed and redeposited at the same site. Osteoblasts, osteoclasts, and possibly their precursors are thought to communicate by chemical messages known as coupling factors. Transforming growth factor β is released from bone during the resorption process; this cytokine helps stimulate subsequent bone formation to fill resorption cavities.[36] It is currently thought that growth factors released from bone mediate the coupling process via a genetic mechanism for activating and suppressing osteoclasts. Thus, *RANK, RANKL,* and *OPG* are gene products that control the remodeling sequence of bone resorption followed by formation. This ubiquitous genetic mechanism appears to be involved in the inflammatory induction of bone resorption and the coupling of bone formation at the same site[37,38] (Figure 10-24).

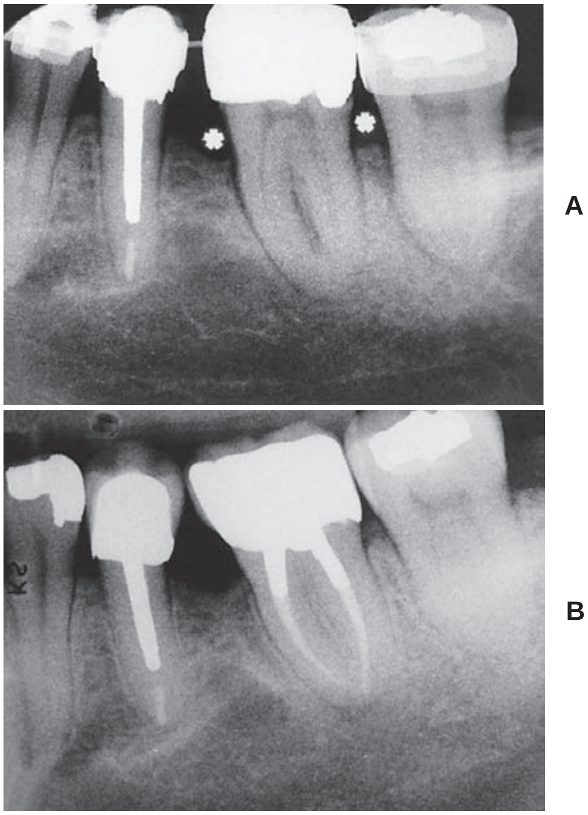


FIGURE 10-21 Periapical radiographs comparing bone maturation at the end of active orthodontic treatment and 2 years later. **A,** At the end of treatment, large amorphous areas of relatively immature bone can be seen. **B,** After retention and restorative treatment, including endodontics, distinct definition of cortices and trabeculae is evident. *(From Roberts WE, et al:* Bone biodynamics in orthodontic and orthopedic treatment: craniofacial growth series, *vol 27, Ann Arbor, 1991, University of Michigan Press.)*

CORTICAL BONE GROWTH AND MATURATION

Enlow[31] sectioned human skulls and histologically identified areas of surface apposition and resorption. The overall patterns of bone modeling ("external remodeling") helped define the mechanisms of facial growth. Although the method could not distinguish between active and inactive modeling sites, it was adequate for determining the overall direction of regional activity in the maxilla and mandible. This method of osseous topography was a considerable advance in the understanding of surface modeling of facial bones.

Melsen[39] used microradiographic images of mineralized sections to extend the capability of the osseous topography method. Patterns of primary and secondary mineralization (as described in Figure 10-20) identified active appositional sites and provided a crude index of bone formation rates. Through the systematic study of autopsy specimens of 126 normal males and females from birth to 20 years of age, the most stable osseous structures in the anterior cranial base of growing children and adolescents were defined anatomically (Figure 10-25, *A*). This research established that the three most stable osseous landmarks for superimposition of cephalometric radiographs are (1) the anterior curvature of the sella turcica, (2) the cribriform plate, and (3) the internal curvature of the frontal bone (Figure 10-25, *B*). In effect, this research established the gold standard for reliable superimposition on the anterior cranial base.

Roberts et al.[10,11,40] introduced simultaneous use of multiple fluorochrome labels and microradiography to assess modeling and remodeling patterns over extended periods of time. Noorda[41] applied these methods for a three-dimensional assessment of subcondylar growth of the mandible of adolescent rabbits. Rabbits 20 weeks of age (early adolescents) were labeled every 2 weeks with a rotating series of six different multifluorochrome labels for 18 weeks. Cross sections of the subcondylar region

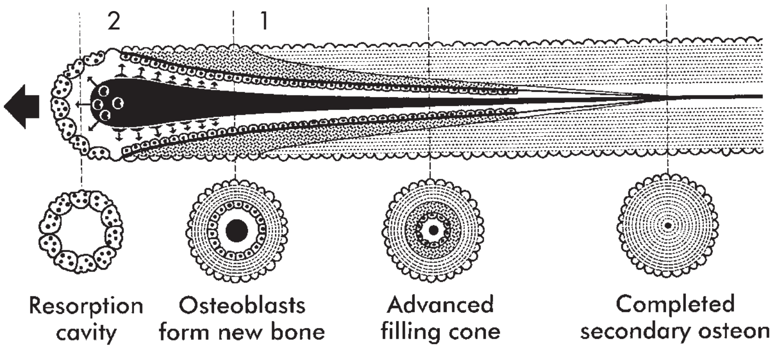


FIGURE 10-22 The cutting/filling cone has a head of osteoclasts that cut through the bone and a tail of osteoblasts that form a new secondary osteon. The velocity through bone is determined by measuring between two tetracycline labels (*1* and *2*) administered 1 week apart. *(Adapted from Roberts WE, et al: Osseous adaptation to continuous loading of rigid endosseous implants,* Am J Orthod *86:95–111, 1984.)*

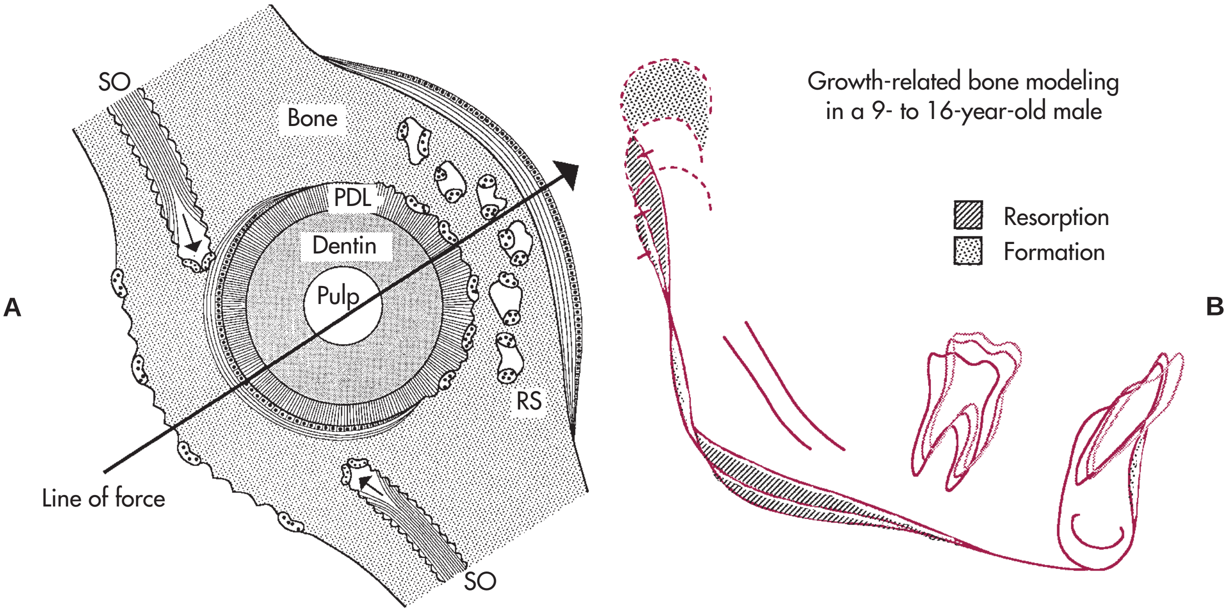


FIGURE 10-23 **A,** Orthodontic bone modeling, or site-specific formation and resorption, occurs along the periodontal ligament (*PDL*) and periosteal surfaces. Remodeling, or turnover, occurs within alveolar bone along the line of force on both sides of the tooth. **B,** Orthopedic bone modeling related to growth in an adolescent male involves several site-specific areas of bone formation and resorption. Although extensive bone remodeling (i.e., internal turnover) also is under way, it is not evident in cephalometric radiographs superimposed on stable mandibular structures.

(Figure 10-26, *A*) were superimposed on original, oldest-labeled, and newest-labeled bone according to fluorescent time markers (Figure 10-26, *B*). Because all three sections were at the same relative level at a point in time, superimposition on original (unlabeled) bone and the oldest labeled bone (Figure 10-26, *C*) provided an index of the relative amounts of bone resorbed and formed as the mandible grew superiorly (Figure 10-26, *D*). This method provided the most accurate assessment to date of cortical bone drift over time. The major mechanism of the increase in interramal width during adolescent growth in rabbits is lateral drift of the entire subchondral region.

The Noorda study also produced important quantitative data on the rates of surface modeling (apposition and resorption) of primary bone (Figure 10-27). During the last 18 weeks of growth to adult stature, the surface apposition rate decreased from more than 25 mm/day to less than 5 mm/day (Figure 10-28, *A*). The secondary osteon census peaked at about 8 to 10 weeks (Figure 10-28, *B*). Thus, under conditions of relatively rapid growth, primary cortical bone is remodeled to secondary osteons in about 2 months. Remodeling therefore is a time-dependent maturation of primary cortical bone.[10,11]

Cutting and Filling Cones

The rate at which cutting and filling cones progress through compact bone is an important determinant of turnover. The progression is calculated by measuring the distance between initiation of labeled bone formation sites along the resorption arrest line in longitudinal sections.[10] Using two fluorescent labels administered 2 weeks apart in adult dogs, the velocity was 27.7 ± 1.9 mm/day (mean ± SEM [standard error of the mean], $n = 4$ dogs, 10 cutting and filling cones sampled from each). At this speed, evolving secondary osteons travel about 1 mm in 36 days. Newly remodeled secondary osteons (formed within the experimental period of the dog study) contained an average of 4.5 labels (administered 2 weeks apart); the incidence of resorption cavities is about one third the incidence of labeled osteons.[40] These data are consistent with a remodeling cycle of about 12 weeks in dogs[40] compared with 6 weeks in rabbits[10] and 17 weeks in human beings.[11,30] This relationship is useful for extrapolating animal data to human applications. More recent experimental studies have shown that new secondary osteons may continue to fix bone labels for up to 6 months, indicating that terminal filling of the lumen is slow.[42]

Traumatic or surgical wounding usually results in intense but localized modeling and remodeling responses. After an osteotomy or placement of an endosseous implant, callus formation and resorption of necrotic osseous margins are modeling processes; however, internal replacement of the devitalized cortical bone surrounding these sites is a remodeling activity. In addition, a gradient of localized remodeling disseminates through

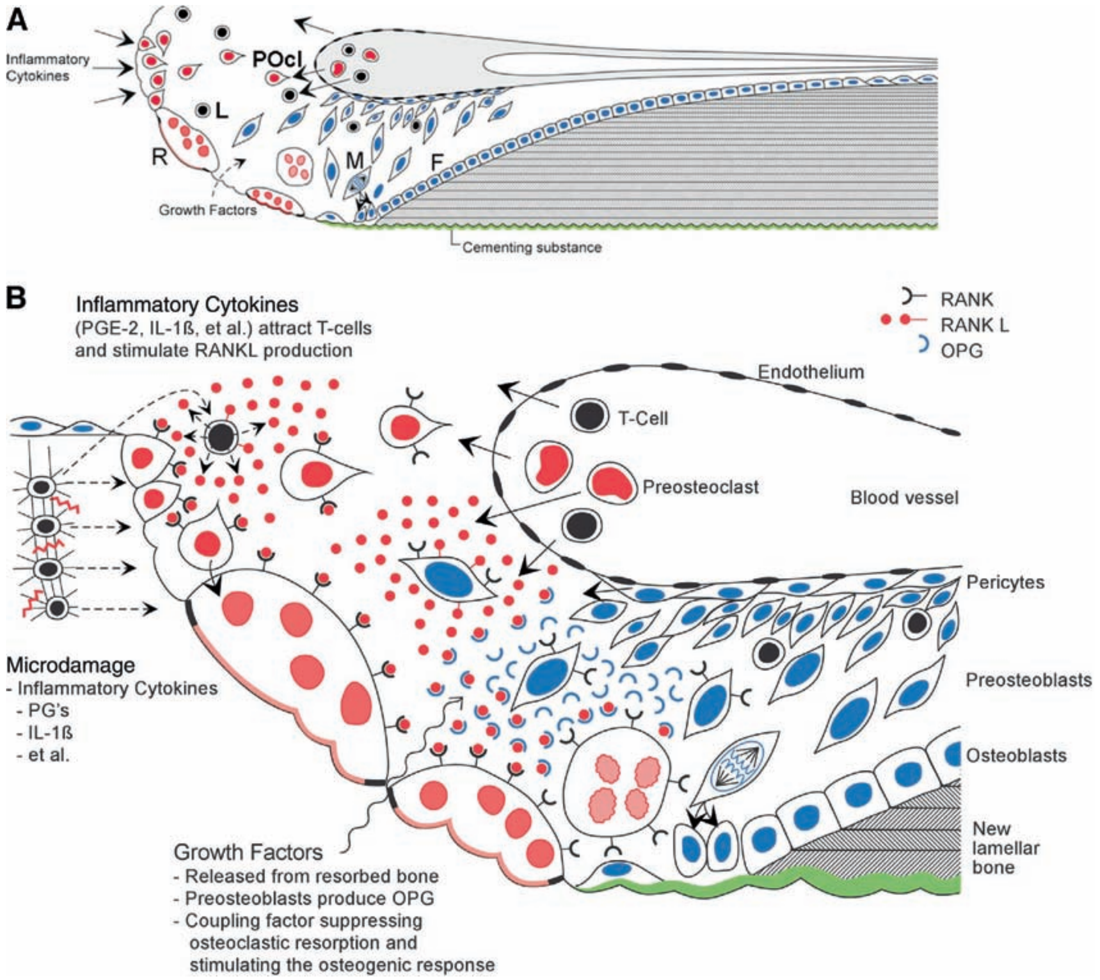


FIGURE 10-24 **A,** A hemisection of a cutting/filling cone moving to the left demonstrates the intravascular and perivascular mechanisms for coupling bone resorption (*R*) to formation (*F*) during the remodeling process. Lymphocytes (*L*) are attracted from the circulation by inflammatory cytokines. They help recruit preosteoclasts (*POcl*) from the circulation. See text for details. **B,** A magnified view of the head of a hemicutting/filling cone illustrates the proposed mechanism for coupling bone resorption to formation via the genetic *RANK*/*RANKL*/*OPG* mechanism. The cutting head is stimulated by inflammatory cytokines produced by osteocytes in damaged bone (*left*). Preosteoclasts have RANK receptors that are bound and activated by RANKL, probably produced or mediated by T cells (lymphocytes) near the resorption front. Growth factors from resorbed bone (*bottom*) stimulate production of preosteoblasts, which then produce OPG to block the RANK receptors on osteoclasts; the latter then withdraw from the scalloped surface and degenerate. Relatively flat mononuclear cells (*bottom center*) form cementing substance to form a resorption arrest line. Osteoblasts (*bottom right*) produce new lamellar bone to fill the resorption cavity. *[From Roberts WE, et al: Remodeling of mineralized tissues, part II: control and pathophysiology,* Semin Orthod *12:238–253, 2006.)*

the bone adjacent to any invasive bone procedure. This process, called *regional acceleratory phenomenon*, is an important aspect of postoperative healing.[30,43] Orthodontists can take advantage of the intense postoperative modeling and remodeling activity (1) to position a maxilla orthopedically with headgear, occlusal biteplates, or cervical support within a few weeks after a LeFort osteotomy and (2) to finish orthodontic alignment of the dentition rapidly after orthognathic surgery.[20,44]

Modeling and remodeling are controlled by an interaction of metabolic and mechanical signals. Bone modeling is largely under the integrated biomechanical control of functional applied loads. However, hormones and other metabolic agents have a strong secondary influence, particularly during periods of growth and advanced aging. Paracrine and autocrine mechanisms, such as local growth factors and prostaglandins, can override the mechanical control mechanism temporarily during wound healing.[45] Remodeling responds to metabolic mediators such as PTH and estrogen primarily by varying the rate of bone turnover. Bone scans with ^{130}Te-bisphosphate, a marker of bone activity, indicate that the alveolar processes, but not the basilar mandible, have a high remodeling rate.[46,47] Uptake of the marker

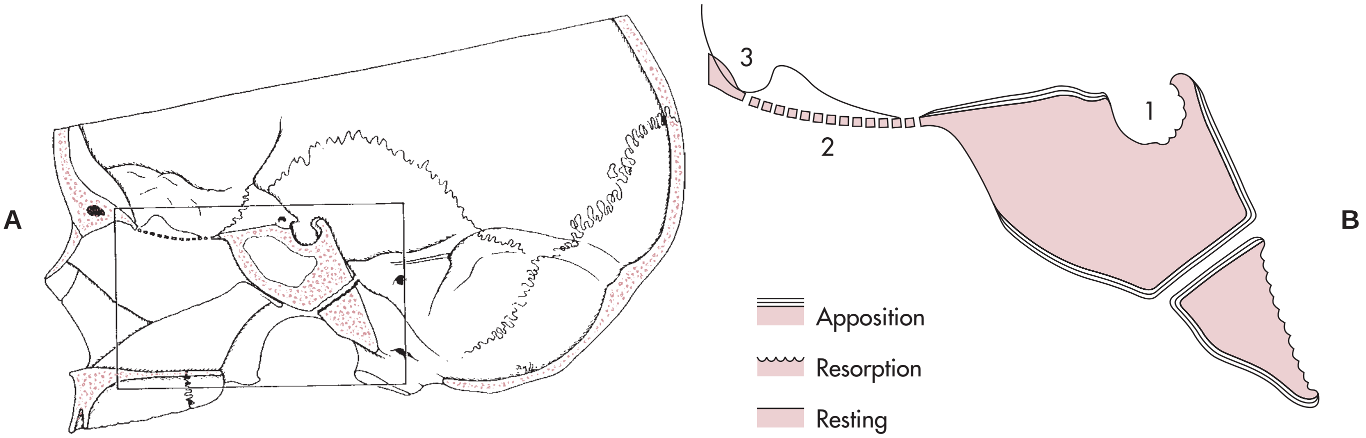


FIGURE 10-25 **A,** Schematic drawing of a skull showing the tissue block removed at autopsy from a series of growing children and adolescents from birth to 20 years of age. **B,** Diagrammatic representation of the bone modeling patterns of the cranial base in growing children. Histologic and microradiographic analysis established that the three most stable anatomic landmarks are (*1*) the anterior curvature of the sella turcica, (*2*) the cribriform plate, and (*3*) the internal curvature of the frontal bone. *(From Melsen B: The cranial base,* Acta Odontol Scand *32(suppl 62):103, 1974.)*

in alveolar bone is similar to uptake in trabecular bone of the vertebral column. The latter is known to remodel at a rate of about 20% to 30% per year compared with most cortical bone, which turns over at a rate of 2% to 10% per year.[48] Metabolic mediation of continual bone turnover provides a controllable flow of calcium to and from the skeleton.

Structural and Metabolic Fractions. The structural fraction of cortical bone is the relatively stable outer portion of the cortex; the metabolic fraction is the highly reactive inner aspect (Figure 10-29, *A*). The primary metabolic calcium reserves of the body are found in trabecular bone and the endosteal half of the cortices. Analogous to orthodontic wires, the stiffness and strength of a bone are related directly to its cross-sectional area. Diaphyseal rigidity quickly is enhanced by adding a circumferential lamella at the periosteal surface. Even a thin layer of new osseous tissue at the periosteal surface greatly enhances bone stiffness because it increases the diameter of the bone. In engineering terms, cross-sectional rigidity is related to the second moment of the area. The same general relationship of round wire diameter and stiffness (strength) is well known to orthodontists. The rigidity of a wire increases as the fourth power of diameter.[49] Thus, when a relatively rigid material (bone or wire) is doubled in diameter, the stiffness increases 16 times.

The addition of new osseous tissue at the endosteal (inner) surface has little effect on overall bone strength. Structurally, the long bones and mandible are modified tubes—an optimal design for achieving maximal strength with minimal mass.[28] Within limits, loss of bone at the endosteal surface or within the inner third of the compacta has little effect on bone rigidity. The inner cortex can be mobilized to meet metabolic needs without severely compromising bone strength (Figure 10-29, *B*); this is the reason patients with osteoporosis have bones with a normal diameter but thin cortices. Even under severe metabolic stress, the body follows a cardinal principle of bone physiology: maximal strength with minimal mass.[50]

BONE METABOLISM

Orthodontists and dentofacial orthopedists manipulate bone. The biomechanical response to altered function and applied loads depends on the metabolic status of the patient. Bone metabolism is an important aspect of clinical medicine that is directly applicable to orthodontics and orthopedics. This section discusses the fundamentals of bone metabolism with respect to clinical practice.

The skeletal system is composed of highly specialized mineralized tissues that have structural and metabolic functions. Structurally, lamellar, woven, composite, and bundle bone are unique types of osseous tissue adapted to specific functions. Bone modeling and remodeling are distinct physiologic responses to integrated mechanical and metabolic demands. Biomechanical manipulation of bone is the physiologic basis of orthodontics and facial orthopedics. However, before addressing dentofacial considerations, an orthodontist must assess the patient's overall health status. Orthodontics is bone manipulative therapy, and favorable calcium metabolism is an important consideration. Because of the interaction of structure and metabolism, a thorough understanding of osseous structure and function is fundamental to patient selection, risk assessment, treatment planning, and retention of desired dentofacial relationships.[50,51]

Bone is the primary calcium reservoir in the body (Figure 10-30). About 99% of the calcium in the body

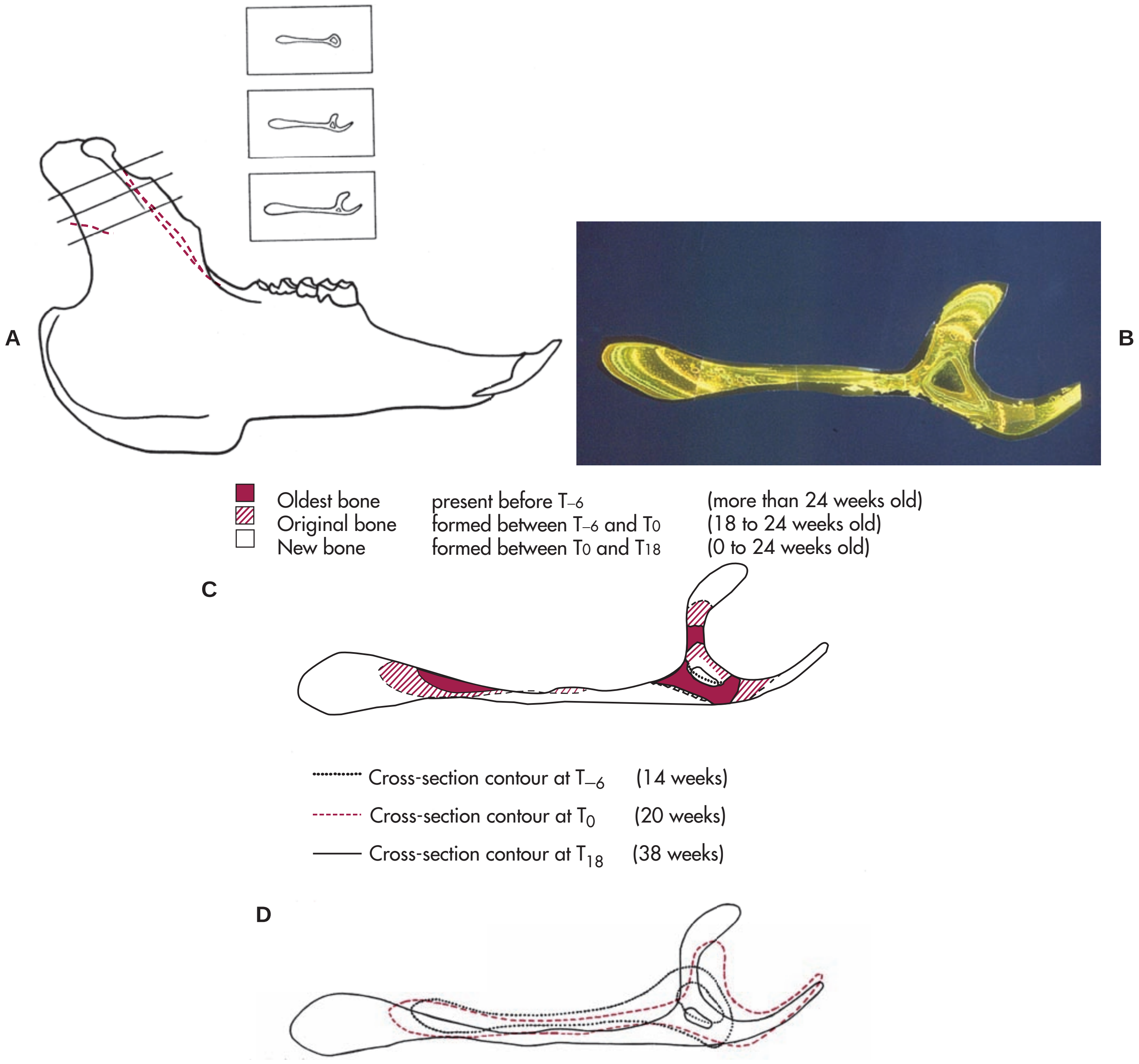

A
B
C
D
Oldest bone present before T–6 (more than 24 weeks old)
Original bone formed between T–6 and T0 (18 to 24 weeks old)
New bone formed between T0 and T18 (0 to 24 weeks old)
Cross-section contour at T–6 (14 weeks)
Cross-section contour at T0 (20 weeks)
Cross-section contour at T18 (38 weeks)

FIGURE 10-26 **A,** Schematic drawing of a rabbit mandible showing the plane of sectioning in the subcondylar region of the ramus. **B,** Fluorescent light photomicrographs of the most inferior section are arranged in a composite. The weekly deposition of bone labels over 4 months shows the patterns of bone modeling and remodeling associated with the growth and development of the subcondylar region. **C,** Based on the uptake of bone labels, the age of specific areas in a given cross section can be determined accurately. **D,** Because the subcondylar region of the ramus is growing superiorly, superimposition of the three sections on the oldest bone gives an estimation of the patterns of bone resorption (catabolic modeling) associated with growth of the mandibular ramus. *(From Noorda CB: Modeling and remodeling in the cortical bone of both growing and mature rabbits, master's thesis, San Francisco, 1986, University of the Pacific.)*

is stored in the skeleton. The continual flux of bone mineral responds to a complex interaction of endocrine, biomechanical, and cell-level control factors that maintain the serum calcium level at about 10 mg/dl (10 mg%).

Calcium homeostasis is the process by which mineral equilibrium is maintained. Maintenance of serum calcium levels at about 10 mg/dl is an essential life support function. Life is thought to have evolved in the sea; calcium homeostasis is the mechanism of the body for maintaining the primordial mineral environment in which cellular processes evolved.[52] Calcium metabolism is one of the fundamental physiologic processes of life support. When substantial calcium is needed to maintain the critical serum calcium level, bone structure is

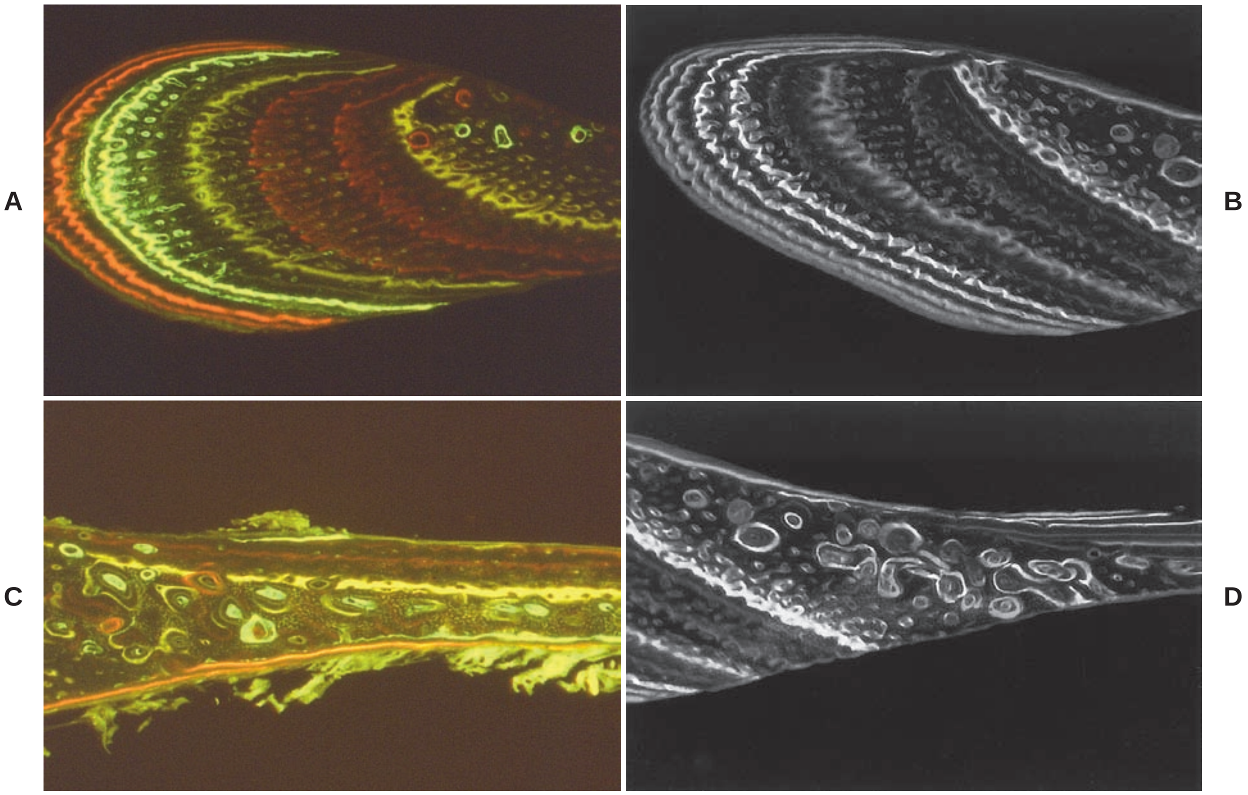


FIGURE 10-27 **A,** Fluorescent microscopy of weekly bone labels shows the patterns of anabolic modeling (bone apposition) in a rabbit. Note the diminishing space between the labels as growth slows and the animal achieves an adult skeletal form. **B,** A similar section from another rabbit in the same study shows the consistency of the growth pattern. **C,** In the first rabbit, the adjacent microscopic field shows several sites of bone remodeling in primary cortical bone formed about 6 to 12 weeks earlier. **D,** In the second rabbit, the adjacent microscopic field shows a consistent pattern of remodeling of new cortical bone at about 6 to 12 weeks after formation. *(From Noorda CB: Modeling and remodeling in the cortical bone of both growing and mature rabbits, master's thesis, San Francisco, 1986, University of the Pacific.)*

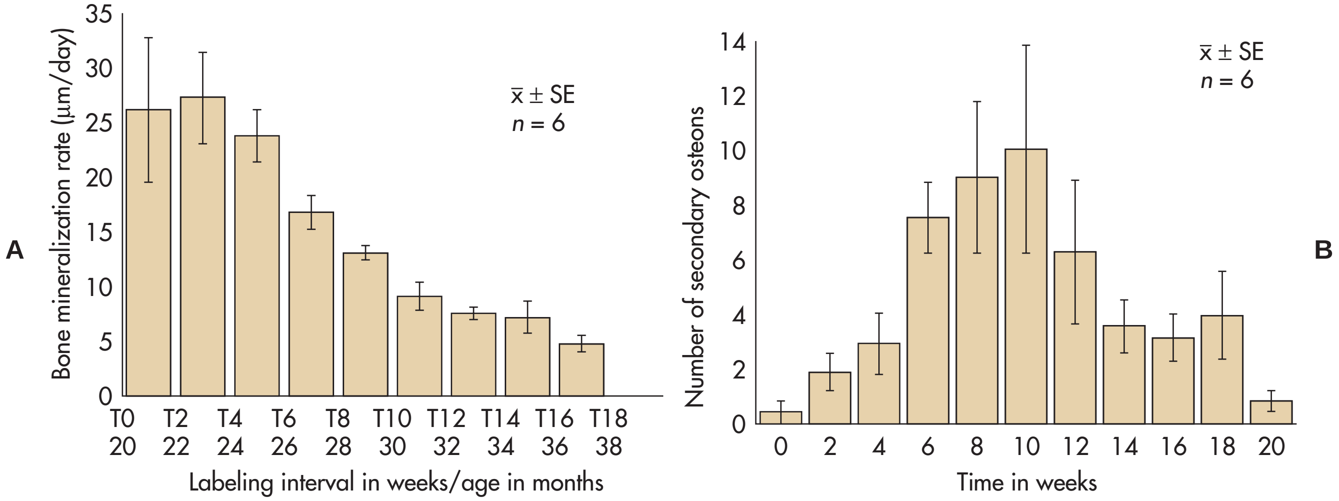


FIGURE 10-28 **A,** Age-related changes in the rate of periosteal apposition that occur in the posterior border of the mandibular ramus of the rabbit. Note the progressive decrease in the rate of periosteal bone apposition as the adolescent animals mature. **B,** Remodeling of new cortical bone. The highest incidence of remodeling to secondary osteons occurs when new cortical bone is 6 to 12 weeks old. *(From Noorda CB: Modeling and remodeling in the cortical bone of both growing and mature rabbits, master's thesis, San Francisco, 1986, University of the Pacific.)*

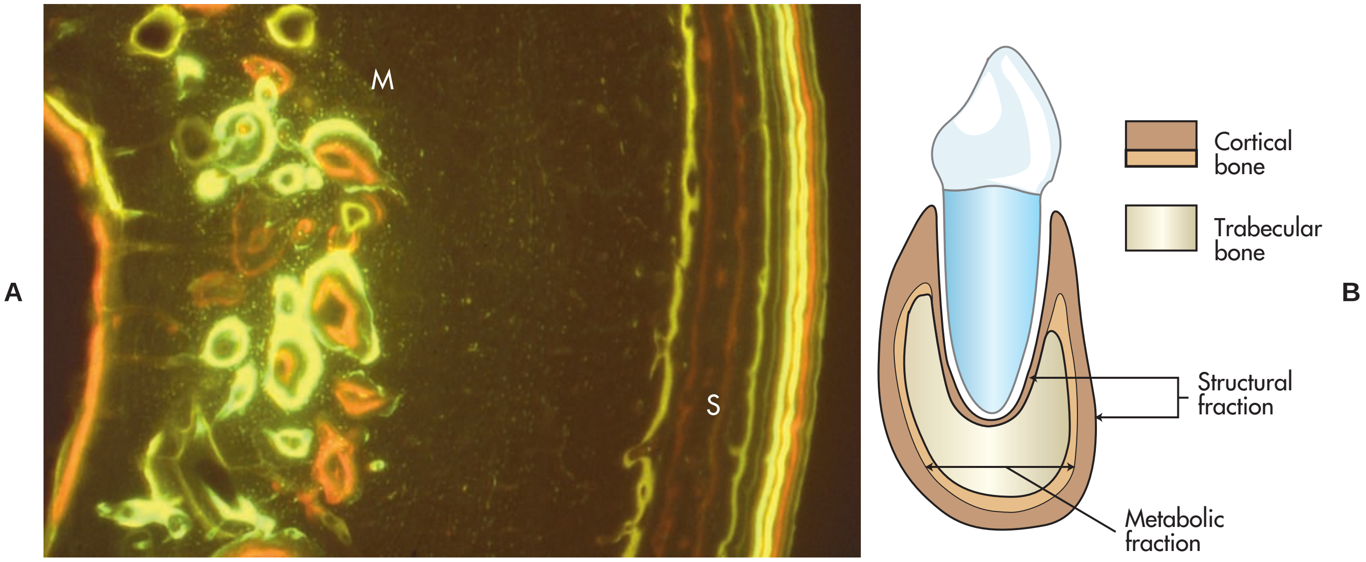


FIGURE 10-29 **A,** The structural (*S*) and metabolic (*M*) fractions of cortical bone are revealed by multiple fluorochrome labeling of a rabbit femur during the late growth and early adult periods. Continuing periosteal bone formation (*right*) contributes to structural strength, and high remodeling of the endosteal half of the compacta provides a continual supply of metabolic calcium. **B,** Structural and metabolic fractions of bone in the mandible. *(Adapted from Roberts WE, et al:* Bone dynamics in orthodontic and orthopedic treatment: craniofacial growth series, *vol 27, Ann Arbor, 1991, University of Michigan Press.)*

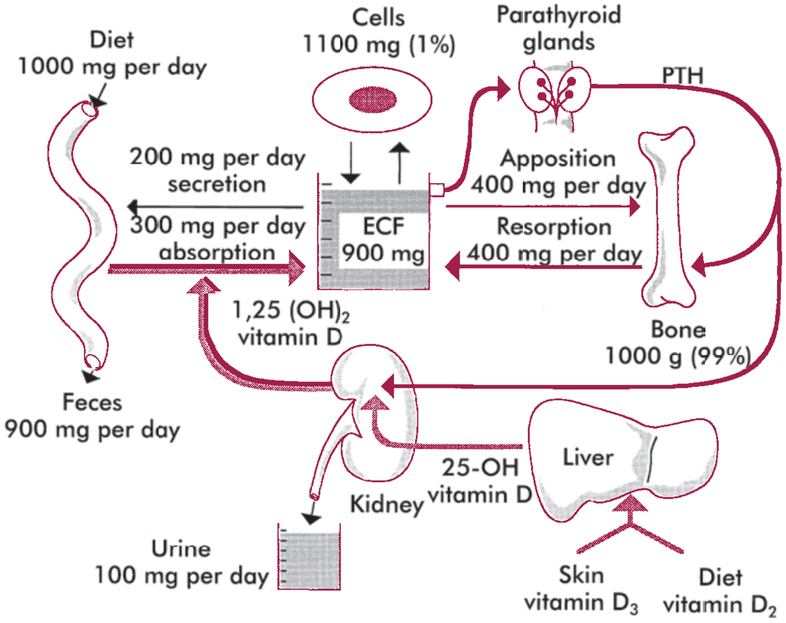


FIGURE 10-30 Calcium metabolism is a complex physiologic process. Maintaining zero calcium balance requires optimal function of the gut, parathyroid glands, bone, liver, and kidneys. Parathyroid hormone (*PTH*) and the active metabolite of vitamin D, 1,25-dihydroxycholecalciferol, are the major hormones involved. *(Adapted from Roberts WE, et al:* Bone dynamics in orthodontic and orthopedic treatment: craniofacial growth series, *vol 27, Ann Arbor, 1991, University of Michigan Press.)*

sacrificed (see Figure 10-30). The alveolar processes and basilar bone of the jaws also are subject to metabolic bone loss.[53] Even in cases of severe skeletal atrophy, the outer cortex of the alveolar process and the lamina dura around the teeth are preserved. This preservation is analogous to the thin cortices characteristic of osteoporosis.

Calcium homeostasis is supported by three temporally related mechanisms: (1) rapid (instantaneous) flux of calcium from bone fluid (which occurs in seconds); (2)

short-term response by osteoclasts and osteoblasts (which extends from minutes to days); and (3) long-term control of bone turnover (over weeks to months). Precise regulation of serum calcium levels at about 10 mg/dl is essential for nerve conductivity and muscle function. A low serum calcium level can result in tetany and death. A sustained high serum calcium level often is a manifestation of hyperthyroidism and some malignancies. Hypercalcemia may lead to kidney stones and dystrophic calcification of soft tissue. Normal physiology demands precise control of the serum calcium level.[51–53]

CALCIUM CONSERVATION

Calcium conservation is the aspect of bone metabolism that involves preservation of skeletal mass. A failure in calcium conservation because of one problem or a combination of metabolic and biomechanical problems may leave a patient with inadequate bone mass for reconstructive dentistry, including orthodontics and orthognathic surgery.

The kidney is the primary calcium conservation organ in the body. Through a complex series of excretion and endocrine functions, the kidney excretes excess phosphate while minimizing the loss of calcium (see Figure 10-30). A patient with impaired renal function often is a high risk for osseous manipulative procedures such as endosseous implants or orthognathic surgery. Because of its components of secondary hyperparathyroidism and impaired vitamin D metabolism, kidney disease may result in poor bone quality, a condition often referred to as renal osteodystrophy.[50,51,54]

Absorption from the small intestine is the primary source of exogenous calcium and phosphate. Phosphate is absorbed passively and rarely is deficient. Optimal calcium uptake, however, requires an active absorption mechanism. A unique factor involved in the gut absorption process is calcium-binding protein, formed in response to the active metabolite of vitamin D.[55] Common clinical profiles associated with poor calcium absorption include a diet deficient in dairy products, vitamin D deficiency, liver disease, and kidney problems.[20,50,51]

Under normal physiologic conditions, the body expends about 300 mg of calcium per day, primarily as a result of secretory processes in the intestines and kidneys. To maintain the serum calcium level, this 300-mg deficit must be recovered by absorption from the gut. However, absorption of calcium from the gut depends on vitamin D and is only about 30% efficient. If less than about 300 mg/day of calcium is absorbed from the intestine, the serum calcium level drops, PTH secretion ensues, and the necessary calcium is removed from the bones (see Figure 10-30).

Positive calcium balance normally occurs during the growing period and for about 10 years thereafter. The skeletal mass of prepubertal children can be enhanced with regular calcium supplements.[56] Peak skeletal mass is attained between 25 and 30 years. After the early adult years, natural aging is associated with a slightly negative calcium balance that progressively erodes bone volume throughout life. Zero calcium balance (see Figure 10-30) is the ideal metabolic state for maintaining skeletal mass. Preservation of bone requires a favorable diet, endocrine balance, and adequate exercise.[50,51]

Diet

Animal studies have documented endosteal bone loss of the alveolar processes of dogs maintained on a low-calcium diet.[52] These data indicate that a low-calcium diet may have severe effects on the bones of the oral cavity. In adult human beings the current recommended daily allowance of calcium is 1000 to 1500 mg/day. Growing adolescents, pregnant or lactating women, and particularly pregnant teenagers need as much as 1500 mg/day. Postmenopausal women who are not receiving estrogen replacement therapy should get 1500 mg of calcium per day. In the United States, dairy products supply about 70% of dietary calcium. As previously mentioned, dietary phosphate deficiency is a rare problem.[20,50,51,57]

Obesity has few health benefits; however, it is a protective factor against osteoporosis. This probably is a result of the high rates of mechanical loading needed to support an overweight body. Slight stature, however, is a risk factor for osteoporosis. Because weight control is a concern for the population at risk, the calcium-to-calorie ratio is an important consideration in dietary counseling. The most favorable dairy products with respect to the calcium-to-calorie ratio are nonfat milk, part-skim mozzarella cheese, Swiss cheese, and plain, low-fat yogurt. Typical servings of these products have about 300 mg of calcium and 100 to 200 calories. Some adults avoid milk because of an intolerance to lactose. These patients often assume that they have a milk allergy, which should be determined according to symptoms. Lactose intolerance usually is manifested by an upset stomach rather than a classic anaphylaxis. Even patients who are intolerant of milk usually can tolerate cultured products such as buttermilk, cheese, and yogurt. Calcium supplements are indicated if a patient is allergic to milk or fails to achieve a calcium-sufficient diet for any other reason. Other foods, particularly green, leafy vegetables (e.g, turnip greens, spinach) contain substantial amounts of calcium, but the calcium is tightly bound and little ionic calcium is absorbed. In effect, to consume adequate calcium in a diet that excludes dairy products is difficult.[50,51]

Calcium supplements of many varieties are available in pharmacies and health food stores, and most provide adequate calcium when used as directed. However, consumers should beware of toxic contaminants in some natural supplements, such as bone meal and dolomite, which may contain significant amounts of lead, arsenic, or other heavy metals. Among the least expensive, readily tolerated supplements are calcium carbonate (e.g., Tums and calcium-rich Rolaids). To determine the amount of elemental calcium in a supplement, consumers must remember to use the molecular weight. For instance, calcium carbonate is only 40% calcium; this means that a 500-mg tablet provides only 200 mg of elemental calcium.[50,51]

Endocrinology

Peptide hormones (e.g., PTH, growth hormone, insulin, and calcitonin) bind receptors at the cell surface and may be internalized with the receptor complex. Steroid hormones (e.g., vitamin D, androgens, and estrogens) are lipid soluble and pass through the plasma membrane to bind receptors in the nucleus.[50,51]

PTH increases serum calcium by direct and indirect vitamin D–mediated effects. Vitamin D (cholecalciferol) originally was thought to be an essential dietary factor. However, vitamin D is not a vitamin at all; it is a hormone. Cholecalciferol is synthesized in skin irradiated by ultraviolet light, hydroxylated in the liver at the No. 25 position, and then hydroxylated in the kidney at the No. 1 position to produce the active metabolite 1,25-DHCC. The last step is feedback controlled; hydroxylation at the No. 1 position is induced by a low serum calcium level, probably through PTH (see Figure 10-30). Clinically, a major effect of 1,25-DHCC is induction of active absorption of calcium from the gut. Because of the complexity of vitamin D synthesis and the metabolic pathway, calcium adsorption may be inhibited at many levels; some of these inhibitors are (1) lack of skin exposure to adequate sunlight of the proper wavelength; (2) failure to consume vitamin D through the diet, thereby not compensating for the lack of vitamin D synthesis; (3) a genetic defect in the skin; (4) liver disease; and (5) kidney failure.[50,51]

Sex hormones have profound effects on bone. Androgens (testosterone and other anabolic steroids) build and maintain musculoskeletal mass. The primary hypertrophic effect of androgens is to increase muscle mass. The anabolic effect on bone is a secondary biomechanical response to increase loads generated by the enhanced muscle mass. Estrogen, however, has a direct effect on bone; it conserves skeletal calcium by suppressing the activation frequency of bone remodeling.[58] At menopause, enhanced remodeling activation increases turnover.[59] Because a slight negative calcium balance is associated with each remodeling event, a substantial increase in the turnover rate can result in rapid bone loss, leading to symptomatic osteoporosis. Even young women are susceptible to significant bone loss if the menstrual cycle (menses) stops.[32] Bone loss is a common problem in women who have low body fat and who exercise intensely (e.g., running or gymnastics) and in women who are anorectic.[60] Clearly, estrogen protects the female skeleton from bone loss during the childbearing years. Lack of menses in women of any age is a high risk factor for the development of osteoporosis later in life.[50,51]

Estrogen replacement therapy (ERT) was widely recommended for calcium conservation and the prevention of osteoporosis in postmenopausal women.[61,62] However, the increased incidence and progression of breast cancer have greatly decreased the use of ERT.[63] The antiestrogen tamoxifen is used to treat some forms of breast cancer. Fortunately, in postmenopausal women tamoxifen has a beneficial effect on bone similar to that of estrogen.[64] Raloxifene (Evista) has been shown to reduce the risk of osteoporosis and heart disease without increasing the risk of breast cancer. Some studies have even shown a substantial anticancer protective effect.[65]

SKELETAL COMPROMISE

Skeletal health is related to diet, exercise, lifestyle, and proper functioning of numerous organ systems. To provide optimal support over a broad spectrum of conditions, the skeletal system has evolved complex mechanical, endocrine, and cell-level regulatory mechanisms. A failure of one or more of these homeostatic mechanisms can result in metabolic bone disease. Low skeletal mass or poor osteogenic capability (or both) may make some patients poor risks for orthodontic or orthognathic procedures. Skeletally compromised patients who seek unrelated dental treatment provide dentists with unique diagnostic opportunities. Timely medical referral of individuals with high-risk profiles can result in substantial health benefits. If osteopenia is confirmed, corrective medical therapy can be started before the onset of the debilitating symptoms associated with osteoporosis.[50,51]

The concept of structural and metabolic fractions (see Figure 10-29) has considerable clinical significance. The dietary requirement for calcium increases during the growing years. A high dietary calcium intake (1200 mg/day) is essential during the adolescent period to provide structural strength without compromising the metabolic reserve. Pregnancy and lactation before the age of 19 may be precipitating factors for osteopenia later in life. Multiple births during the teenage years are of particular concern. Under these circumstances, young women may fail to deposit sufficient skeletal reserves to withstand the sustained negative calcium balance that follows menopause.[50,51,66]

Although the metabolic fraction of cortical bone can make a substantial contribution, the major source of serum calcium under steady-state conditions is trabecular bone. The primary reason for this is the differential remodeling rates. Cortical bone turns over about 2% to 10% per year, whereas trabecular bone, which is much more active, remodels at 20% to 30% per year.[48] Because it is more labile, trabecular bone is more susceptible to loss under conditions of negative calcium balance. For this reason, patients with osteoporosis have a tendency to suffer structural failure at sites primarily dependent on trabecular bone: the spine (compression fracture), the wrist (Colles fracture), and the hip (femoral neck fracture). Degenerative changes in the TMJ have not been related directly to skeletal atrophy. However, some relationship is likely because these problems tend to affect the same high-risk group—postmenopausal women.[50,51,67]

Women depend on estrogen to maintain skeletal mass during the reproductive years. Lack of normal menses, even in young women, usually indicates an estrogen deficiency and probable negative calcium balance. About 20% of postmenopausal women will develop frank osteoporosis, and as many as 50% will have some signs or symptoms.[51] All health care providers should be concerned particularly about the skeletal status of postmenopausal white and Asian women. However, even low-risk groups, such as men and black women, have an incidence of osteoporosis that approaches 5%. Osteopenia and osteoporosis therefore are significant health risks for almost everyone. Bone metabolic evaluation is an important diagnostic concern for all patients being considered for orthodontics or orthognathic surgery.[20,44,50]

METABOLIC BONE DISEASE

Osteoporosis is a generic term for very low bone mass (osteopenia). The most important risk factor for the development of osteoporosis is age: after the third decade, osteopenia is related directly to longevity. Other high-risk factors are (1) a history of long-term glucocorticoid treatment, (2) slight stature, (3) smoking, (4) menopause or dysmenorrhea, (5) lack of or little physical activity, (6) low-calcium diet, (7) excessive consumption of alcohol, (8) vitamin D deficiency, (9) kidney failure, (10) liver disease (cirrhosis), and (11) a history of fractures. These risk factors are effective in identifying 78% of those with the potential for osteopenia.[67,68] This is a good screening method for skeletally deficient dental patients. However, one must realize that more than 20% of individuals who eventually develop osteoporosis have a negative history for known risk factors. Any clinical signs or symptoms of low bone mass (e.g., low radiographic density of the jaws, thin cortices, or excessive bone resorption) are grounds for referral. A thorough medical workup, including a bone mineral density measurement, usually is necessary to establish the diagnosis of osteopenia. The term *osteoporosis* usually is reserved for patients with evidence of fracture or other osteoporotic symptoms. The treatment of metabolic bone diseases such as osteoporosis depends on the causative factors. Medical management of these often complex disorders is best handled by physicians specifically trained in bone metabolism.[50,51]

An increasing number of adults are seeking orthodontic treatment. Because all orthodontic and facial orthopedic therapy requires bone manipulation, orthodontists should have a detailed knowledge of bone physiology. All health care practitioners can play an important role in screening patients with high-risk lifestyles. Arresting the progression of metabolic bone disease is preferable to treating the condition after debilitating symptoms appear. A carefully collected history is the best screening method for determining which patients should be referred for a thorough metabolic workup. No age limit is specified for orthodontic treatment; however, clinicians must assess carefully the probability of metabolic bone disease.[50,51] In addition to osteoporosis, orthodontists should be particularly vigilant for osteomalacia, a disease of poor bone mineralization associated with vitamin D deficiency,[48] and for renal osteodystrophy, a related condition in patients with compromised kidney function.[54]

Orthodontics usually is contraindicated in patients with active metabolic bone disease because of excessive resorption and poor rates of bone formation. However, if the metabolic problems (particularly negative calcium balance) are resolved with medical treatment, these patients can be treated orthodontically, assuming that sufficient skeletal structure remains. In fact, some individuals with osteoporosis retain near-normal jaw and alveolar bone, probably because they have healthy oral structures that are loaded normally. Apparently, under these circumstances, the disease preferentially attacks bone and other parts of the body with a less optimal mechanical environment.[50,51]

Because the loss of teeth is an important risk factor for osteoporosis, dental patients, especially adult women, are at high risk for developing osteoporosis. A study of all adult female dental patients at Indiana University School of Dentistry showed that about 65% were at high risk for developing osteoporosis (these women were estrogen deficient or had at least two other risk factors).[69]

Osteoporosis is the most common metabolic bone disease, but orthodontics patients can be affected by many other osseous pathologies, such as renal osteodystrophy, hyperparathyroidism, hypoparathyroidism, hyperthyroidism, and osteomalacia osteogensis imperfecta. In addition, bone can be compromised by a number of other systemic diseases. See Roberts et al.[22] for an orthodontically oriented review.

BIOMECHANICS

Mechanical loading is essential to skeletal health. An essential element of bone biomechanics is the inflammatory control of bone development, the adaptation to applied loads, and the response to pathological challenges. The physiologic mechanism for controlling bone morphology involves inherent (genetic) and environmental (epigenetic) factors. There are three genetic mechanisms: (1) growth and ischemic factors, (2) vascular induction and invasion, and (3) mechanically induced inflammation. The latter two are influenced by two major physical influences: (1) diffusion limitation for maintaining viable osteocytes, and (2) mechanical loading history (Figure 10-31).[1]

Both bone formation and resorption are controlled at the cellular level by inflammatory mechanisms.[70] Thus, inflammation is an important factor in the mediation of bone physiology and pathology. Normal bone modeling and remodeling are controlled by inflammatory processes, both from a direct and indirect perspective. The P2X7 receptor is an important genetic mechanism for production of inflammatory cytokines. It plays a crucial role in bone biology and inflammation, but it has no significant effect on teeth or alveolar bone morphology.[71] Thus, P2X7 knockout mice (animals with a deactivated gene) are a good model for defining the role of inflammatory cytokines in the tooth movement and alveolar adaptation to orthodontics loads. Skeletal adaptations, such as the orthodontic response, are related to the principal stress patterns in the periodontal ligament, and the P2X7 receptor plays a significant role in their mechanotransduction.[72]

Experiments in mice with deactivated *P2X7* genes have demonstrated that a principal function of the gene to be the promotion of necrotic tissue metabolism, by ensuring a normal acute-phase inflammatory response. An increased pattern of functional loading generates damage in affected musculoskeletal tissue, and there is a subsequent pain response that limits function during the initial healing stage. All forms of musculoskeletal adaptation to functional and applied loads involves an interaction of inflammatory mechanisms to stimulate bone cell activity, heal tissue damage, and limit function during the adaptive process. However, it is important to remember that the genetic mechanisms active in bone have interactive functions throughout the body. The receptor–activator system of NF-κB ligand (TNFSF11, also known as RANKL, OPGL, TRANCE and ODF), as well as the tumor necrosis factor (TNF)-family receptor RANK, are essential regulators of bone remodeling. Recently, RANKL and RANK were found to have an essential role in the brain in initiating fever,[73] another important inflammatory mechanism. Thus, genetic inflammatory mechanisms controlling bone physiology are just beginning to be understood at the systemic level. Control of most bone modeling and some remodeling processes are related to strain history, which usually is defined in microstrain (με) (deformation per unit length × 10^{-6}).[74] Repetitive loading generates a specific response, which is determined by the peak strain.[75–79] In an attempt to simplify the often conflicting data, Frost[80] proposed the mechanostat theory. Reviewing the theoretic basis of this theory, Martin and Burr[29] proposed that (1) subthreshold loading of less than 200 με results in disuse atrophy, manifested as a decrease in modeling and an increase in remodeling; (2) physiologic loading of about 200 to 2500 με is associated with normal, steady-state activities; (3) loads exceeding the minimal effective strain (about 2500 με) result in a hypertrophic increase in modeling and a concomitant decrease in remodeling; (4) after peak strains exceed about 4000 me, the structural integrity of bone is threatened, resulting in pathologic overload. Figure 10-32 is a representation of the

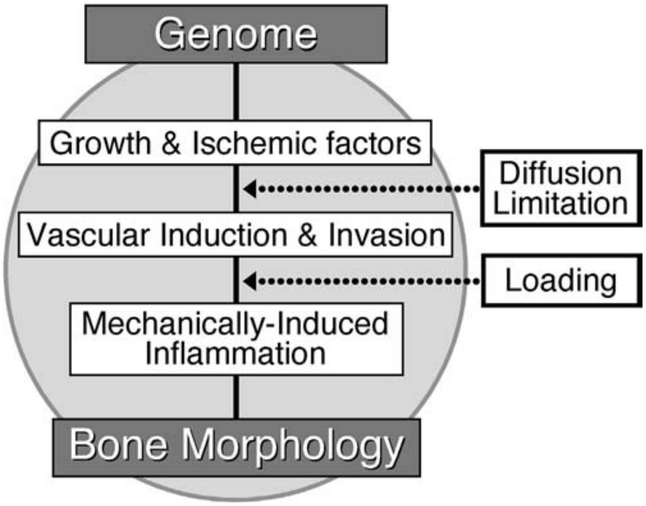

Genome
Growth & Ischemic factors
Vascular Induction & Invasion
Mechanically-Induced Inflammation
Bone Morphology
Diffusion Limitation
Loading

FIGURE 10-31 The genome dictates bone morphology by a sequence of three genetic mechanisms: (*1*) growth and ischemic factors, (*2*) vascular induction and invasion, and (*3*) mechanically induced inflammation. The latter two are influenced by two major physical influences: (*1*) diffusion limitation for maintaining viable osteocytes and (*2*) mechanical loading history. *(From Roberts WE, Hartsfield JK: Bone development and function: genetic and environmental mechanisms,* Semin Orthod *10(2):102, 2004.)*

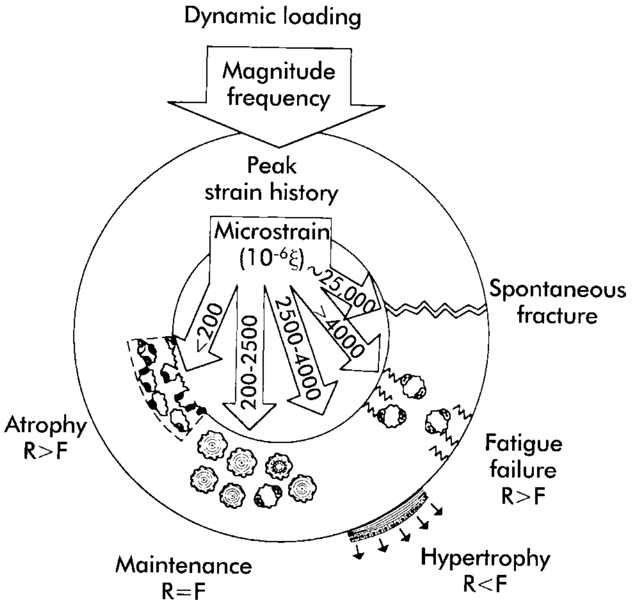


FIGURE 10-32 The mechanostat concept of Frost[58] as defined by Martin and Burr.[29] Bone formation (*F*) and resorption (*R*) are the modeling phenomena that change the shape or form (or both) of a bone. The peak strain history determines whether atrophy, maintenance, hypertrophy, or fatigue failure occurs. Note that the normal physiologic range of loading (Maintenance R+F) is only at less than 10% of maximal bone strength (spontaneous fracture). Fatigue damage can accumulate rapidly at greater than 4000 με.

mechanostat. Many of the concepts and microstrain levels are based on experimental data.[29] The strain range for each given response probably varies between species and may be site specific in the same individual.[20,29,75,77,79] However, the mechanostat provides a useful clinical reference for the hierarchy of biomechanical responses to applied loads.

Normal function helps build and maintain bone mass. Suboptimally loaded bones atrophy as a result of increased remodeling frequency and inhibition of osteoblast formation.[81] Under these conditions, trabecular connections are lost and cortices are thinned from the endosteal surface. Eventually the skeleton is weakened until it cannot sustain normal function. An increasing number of adults with a history of osteopenia caused by metabolic bone disease are seeking orthodontic treatment for routine malocclusions. Assuming that the negative calcium balance is corrected and adequate bone structure remains, patients with a history of osteoporosis or other metabolic bone disease are viable candidates for routine orthodontic therapy. The crucial factor is the residual bone mass in the area of interest after the disease process has been arrested (Figure 10-33).

When flexure (strain) exceeds the normal physiologic range, bones compensate by adding new mineralized tissue at the periosteal surface. Adding bone is an essential compensating mechanism because of the inverse relationship between load (strain magnitude) and the fatigue resistance of bone.[82] When loads are less than 2000 με, lamellar bone can withstand millions of loading cycles, more than a lifetime of normal function. However, increasing the cyclic load to 5000 με, about 20% of the

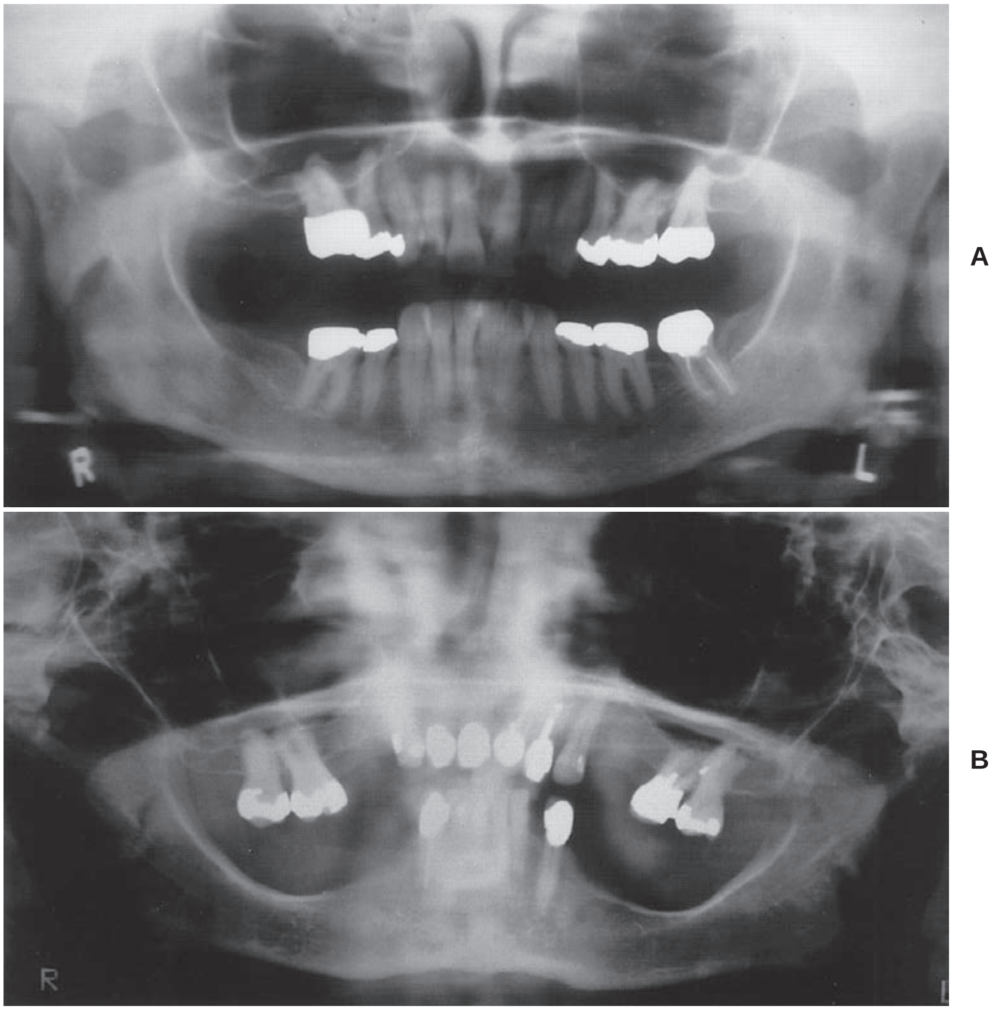


FIGURE 10-33 Two postmenopausal women with systemic osteopenia present widely varying patterns of lower posterior bone loss. **A,** Alveolar bone in the buccal segments is well preserved by functional loading of natural teeth. **B,** Severe resorption of the alveolar process and basilar mandible has occurred in the absence of adequate functional loading. *(From Roberts WE: Fundamental principles of bone physiology, metabolism and loading. In Naert I, et al., editors:* Osseointegration in oral rehabilitation*, London, 1993, Quintessence.)*

ultimate strength of cortical bone, can produce fatigue failure in a 1000 cycles, which is achieved easily in only a few weeks of normal activity. Repetitive overload at less than one fifth of the ultimate strength of lamellar bone (25,000 με, or 2.5% deformation) can lead to skeletal failure, stress fractures, and shin splints.

From a dental perspective, occlusal prematurities or parafunction may lead to compromise of periodontal bone support. Localized fatigue failure may be a factor in periodontal clefting, alveolar recession, tooth oblation (cervical ditching), or TMJ arthrosis. Guarding against occlusal prematurities and excessive tooth mobility, while achieving an optimal distribution of occlusal loads, are important objectives for orthodontic treatment. The human masticatory apparatus can achieve a biting strength of more than 2200 N, or more than 500 lb of force.[83,84] Because of the high magnitude and frequency of oral loads, functional prematurities used during orthodontic treatment could contribute to isolated incidences of alveolar clefting (Figure 10-34, *A*) and root resorption (Figure 10-34, *B*). Excessive tooth mobility should be monitored carefully during active orthodontic treatment and retention. Prevention of occlusal prematurities is a particular concern in treating periodontally compromised teeth.

SUTURES

The facial sutures are important mediators of skeletal adaptation to craniofacial growth and biomechanical therapy.[85] Mechanical forces, both functional and therapeutic, regulate sutural growth by inducing sutural mechanical strain.[86] Expansion of the midpalatal suture often is a key objective in dentofacial orthopedic treatment. Although the potential for sutural expansion has been appreciated since the middle of the nineteenth century, Andrew Haas[87] introduced the modern clinical concepts of rapid palatal expansion (RPE) in the last half of the twentieth century. RPE is very effective in growing children but the skeletal response of the craniofacial sutures of adults is questionable. The nonsurgical RPE of young adult females was documented with a bone scintigraphy study, demonstrating a bone metabolic pattern consistent with both dental and skeletal effects.[7] Biomechanics studies using finite element models have helped explain the highly variable clinical reactions in adults depending if sutures are patent or fused.[88] Despite the long history of palatal expansion, little was known of the cell kinetics of osteogenesis and the bone remodeling response associated with it. Sutures and the PDL were widely assumed to have similar mechanisms of osseous adaptation. Chang et al.[89,90] compared the osteogenic reaction in the expanded midpalatal suture with orthodontically induced osteogenesis in the PDL of adjacent incisors (Figures 10-35 to 10-38). The widened PDL resulted in direct osteogenic induction of new bone,

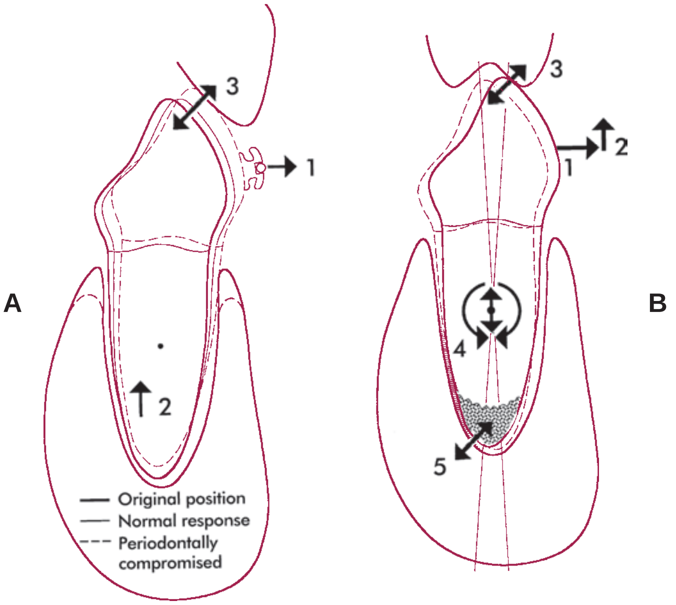


FIGURE 10-34 **A,** A moderate load in the buccal direction (*1*) results in tipping displacement of the crown. In the absence of vertical constraint, a normal healthy tooth would be expected to extrude slightly because of the inclined plane effect of the root engaging the tapered alveolus (*2*). As a result of diminished bone support and destruction of restraining collagen fibers at the alveolar crest, a periodontally compromised tooth may tip and extrude considerably more. Depending on the occlusion, this displacement may cause an occlusal prematurity (*3*). **B,** Orthodontic tipping (*1*) with an extrusive component (*2*) may produce an occlusal prematurity (*3*) and mobility (*4*). An individual tooth in chronic occlusal trauma is expected to fatigue the root apex continuously. This combination of physical failure in a catabolic environment may lead to progressive root resorption (*5*).

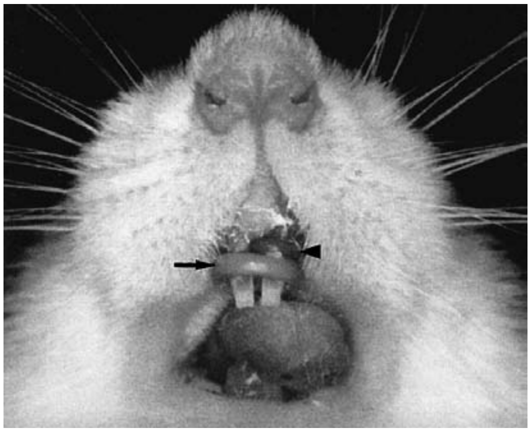


FIGURE 10-35 An expansion appliance is placed on the maxillary incisors of a rat. A 1-mm-diameter elastomeric ring (*arrowhead*) was fitted into the left incisor; a 2-mm-diameter elastomeric ring (*arrow*) encircled both incisors, 2 mm from cutting edges. The 2-mm ring constricts the incisors while the interproximal elastic elicits a parallel separation of the interpremaxillary suture. *(From Chang H-N, et al: Angiogenesis and osteogenesis in an orthopedically expanded suture,* Am J Orthod Dentofac Orthop *3(4):383, 1997.)*

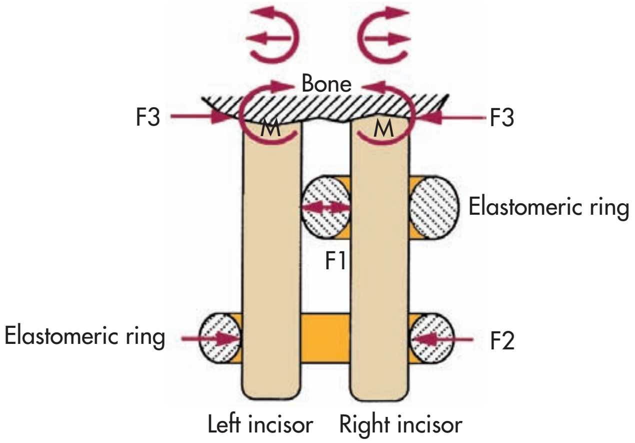


FIGURE 10-36 Forces (*F*) and moments (*M*) on a tooth. *F1* and *F2* were produced by inner and outer elastomeric rings, respectively. This illustration of the device demonstrates the formation of a couple that resulted in parallel separation of the interpremaxillary suture. As measured in a pilot study using a Dontrix tension gauge, the outer elastomeric ring exerted about 200 *g* of initial separation force *(F2)*, of which 90 *g* remained at the end of day 3. This force level (90 *g*) is suitable for premaxillary expansion in rats. *(From Chang H-N, et al: Angiogenesis and osteogenesis in an orthopedically expanded suture,* Am J Orthod Dentofac Orthop *3(4):383, 1997.)*

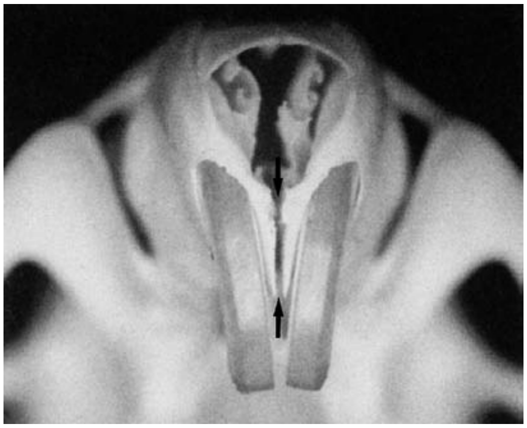


FIGURE 10-37 A dry skull expanded as illustrated in Figure 10-36 shows parallel separation of the interpremaxillary suture (*arrow*). *(From Chang H-N, et al: Angiogenesis and osteogenesis in an orthopedically expanded suture,* Am J Orthod Dentofac Orthop *3(4):383, 1997.)*

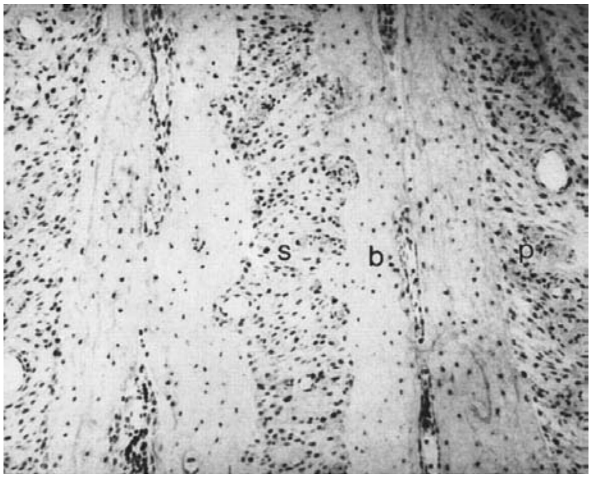


FIGURE 10-38 Photomicrograph of a sagittal section of the interpremaxillary suture, showing the relationship of expanded suture (*s*), alveolar bone (*b*), and periodontal ligament (*p*). (Stained with hematoxylin and eosin; original magnification ×40.) *(From Chang H-N, et al: Angiogenesis and osteogenesis in an orthopedically expanded suture,* Am J Orthod Dentofac Orthop *3(4):383, 1997.)*

whereas the adjacent expanded suture experienced hemorrhage, necrosis, and a wound healing response. Vascular invasion of the blood clot in the expanded suture was a prerequisite for new bone formation. Chang et al.[90] also defined the angiogenic capillary budding process associated with the propagation of perivascular osteogenic cells (Figure 10-39). After its vascularity had been reestablished, the expanded midpalatal suture and adjacent widened PDL produced new osteoblasts by the same mechanism. Pericytes, the osteogenic cells that are perivascular to the venules (Figure 10-40), are the cells of origin for preosteoblasts. This vascularly mediated osteogenic mechanism for producing osteoblasts was described earlier in this chapter (for the detailed cell kinetic analysis that established this important mechanism, see Chang et al.[89,90]).

The role of perivascular cells in the origin of PDL osteoblasts first was reported in 1987.[91] Over the past decade a number of investigators have reported the same mechanism for the production of osteoblasts throughout the body. Doherty et al.[92] recently reviewed the literature and provided evidence that vascular pericytes express osteogenic potential in vivo and in vitro. What is now clear is that perivascular osteogenesis is not a mechanism unique to the PDL and sutures but rather it is the source of osteoblasts all over the body under a variety of osteogenic conditions.

Parr et al.[93] used an innovative endosseous implant mechanism to expand the nasal bones in young adult rabbits with forces from 1 to 3 N. Injection of multiple fluorochrome bone labels documented the bone modeling and remodeling reactions that occurred not only adjacent to the suture but also throughout the nasal bones. Expansion of a suture results in a regional adaptation of adjacent bones similar to the postoperative regional acceleratory phenomenon that is characteristic of bone wound healing.[29] Parr et al.[93] described the bone formation rate and mineral apposition rate for new bone formed in the suture (Figures 10-41 to 10-43). Sutural expansion, relative to load decay, is shown for repeatedly reactivated 1- to 3-N loads (Figure 10-44). Osseointegrated implants were excellent abutments for sutural expansion mediated by loads as large as 3 N.

Overall, expanded sutures are less efficient at initiating osteogenesis because of postactivation necrosis.[89]

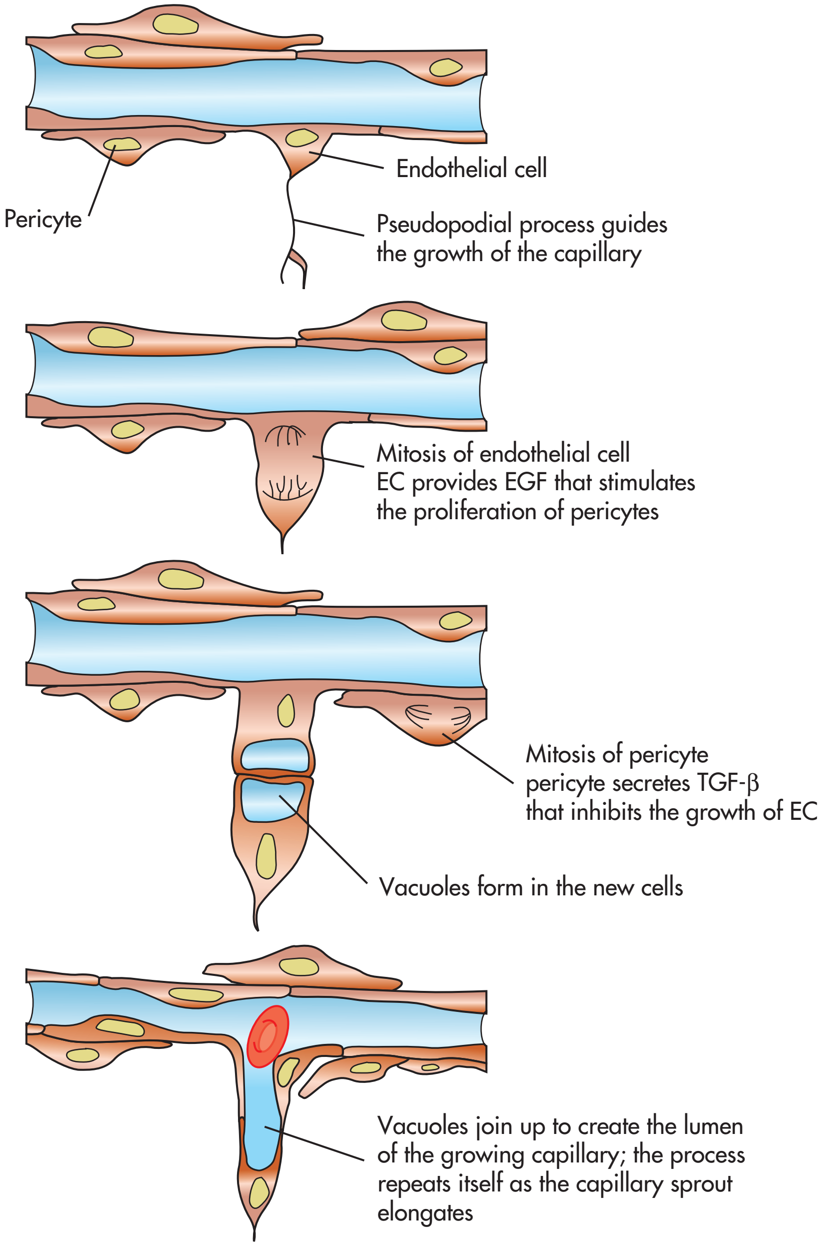

Endothelial cell
Pericyte
Pseudopodial process guides the growth of the capillary
Mitosis of endothelial cell
EC provides EGF that stimulates the proliferation of pericytes
Mitosis of pericyte
pericyte secretes TGF-β that inhibits the growth of EC
Vacuoles form in the new cells
Vacuoles join up to create the lumen of the growing capillary; the process repeats itself as the capillary sprout elongates

FIGURE 10-39 Angiogenesis involves a well-defined sequence of capillary budding followed by an extension of the perivascular network of pericytes, which are the source of osteoprogenitor cells. *EC,* Endothelial cell; *EGF,* epidermal growth factor; *TGF-b*, transforming growth factor β. *(Redrawn from Chang H-N, et al: Angiogenic induction and cell migration in an orthopaedically expanded maxillary suture in the rat,* Arch Oral Biol *41(10):986, 1996.)*

However, after a wound healing response has occurred to reestablish sutural vitality, the vascularly mediated origin of osteoblasts is the same as for the PDL and other skeletal sites. Expansion of a suture results in a regional acceleration of bone adaptive activity, which allows for extensive adaptation of the affected bones to new biomechanical conditions. These results indicate that sutural expansion within physiologic limits is a clinically viable means of repositioning the bones of the craniofacial complex to improve aesthetics and function. With respect to fundamental bone physiology, sutural expansion is similar to surgically mediated distraction osteogenesis. Using sequential labels of ^{3}H-thymidine and bromodeoxyuridine in rabbits, Sim[94] demonstrated that the osteoblast histogenesis sequence for evolving secondary osteons was a perivascular process (Figure 10-45) similar to that previously demonstrated for the PDL[95] and the intermaxillary suture.[89,90] The Sim data confirmed the hypothesis that the perivascular connective tissue cells proliferate and migrate along the surface of the invading

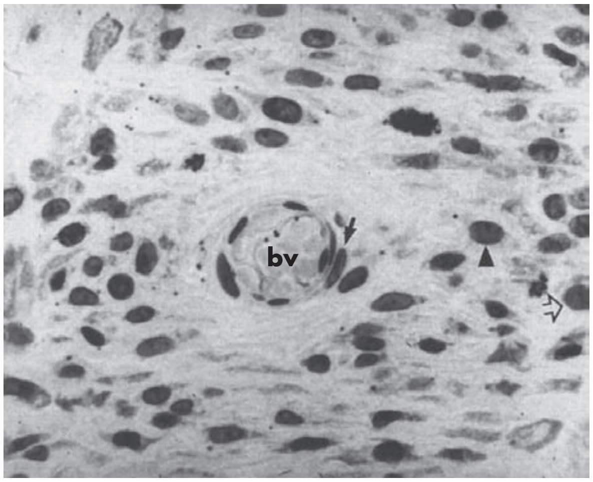


FIGURE 10-40 Photomicrograph of autoradiography of an expanded interpremaxillary suture, showing blood vessel (*bv*) and paravascular cells. Note the relationship of pericyte (*solid arrow*), fibroblast-like cells (*arrowhead*), and mature osteoblast (*open arrow*) lining the suture–bone interface. (Stained with hematoxylin and eosin; original magnification ×400.) *(From Chang H-N, et al: Angiogenesis and osteogenesis in an orthopedically expanded suture,* Am J Orthod Dentofac Orthop *3(4):383, 1997.)*

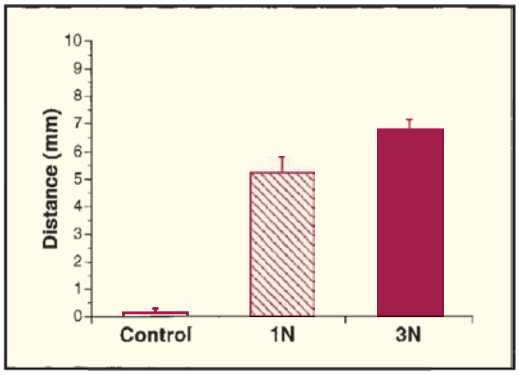


FIGURE 10-41 Expansion of the suture between the nasal bones of a rabbit is expressed as the mean difference of initial and final measurements between implants for the three loading groups (mean ± SEM, all groups significant at $p < .05$.). *(From Parr JA, et al: Sutural expansion using rigidly integrated endosseous implants: an experimental study in rabbits,* Angle Orthod *67(4):287, 1987.)*

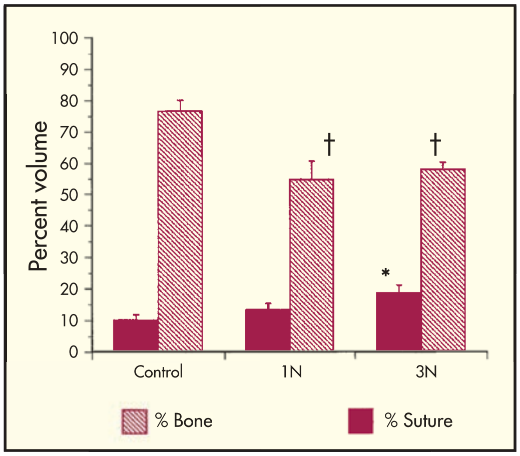


FIGURE 10-42 Volume percent of suture and bone for three loading groups (mean ± SEM); an asterisk (*) indicates significant difference in the percentage of sutural expansion from the control at $p < .05$; a dagger (†) indicates significant difference in the percentage of bone from the control at $p < .05$. *(From Parr JA, et al: Sutural expansion using rigidly integrated endosseous implants: an experimental study in rabbits,* Angle Orthod *67(4):287, 1987.)*

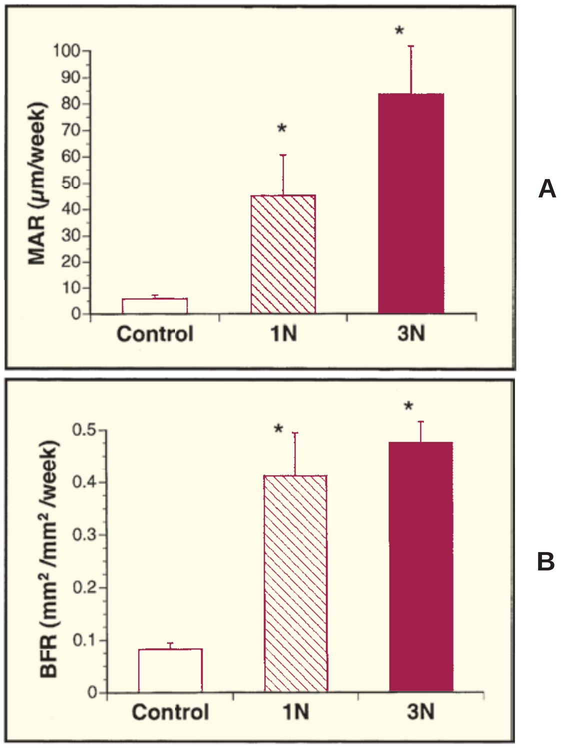


FIGURE 10-43 **A,** Mineral apposition rate (MAR). **B,** The bone formation rate (BFR) was calculated at the suture during the final 6 weeks of loading for three loading groups (mean ± SEM; an asterisk [*] indicates significant difference from the control at $p < .05$.] *(From Parr JA, et al: Sutural expansion using rigidly integrated endosseous implants: an experimental study in rabbits,* Angle Orthod *67(4):287, 1987.)*

capillaries or venules. Figure 10-46 is a three-dimensional perspective of a remodeling foci (cutting/filling cone) in cortical bone, which demonstrates that perivascular cells, near the head of the proliferating blood vessel, are the source of osteoblasts for the filling cone. Confirmation of a perivascular origin of osteoblasts in PDL, sutures, and cortical bone remodeling foci strongly suggests that all osteoblasts, at least in the peripheral skeleton, are derived from perivascular precursors. These data suggest that less differentiated osteogenic cells grow along the surface of bone-related blood vessels (capillaries and venules) as they invade blood clots or other connective tissue spaces in preparation for osteogenesis. From a clinical perspective, the perivascular origin of osteoblasts confirms an important surgical principle: preservation of the blood supply is essential for optimal healing of bone.

Maxillary protraction in skeletal Class III patients is particularly effective in the mixed dentition,^{96} but bone

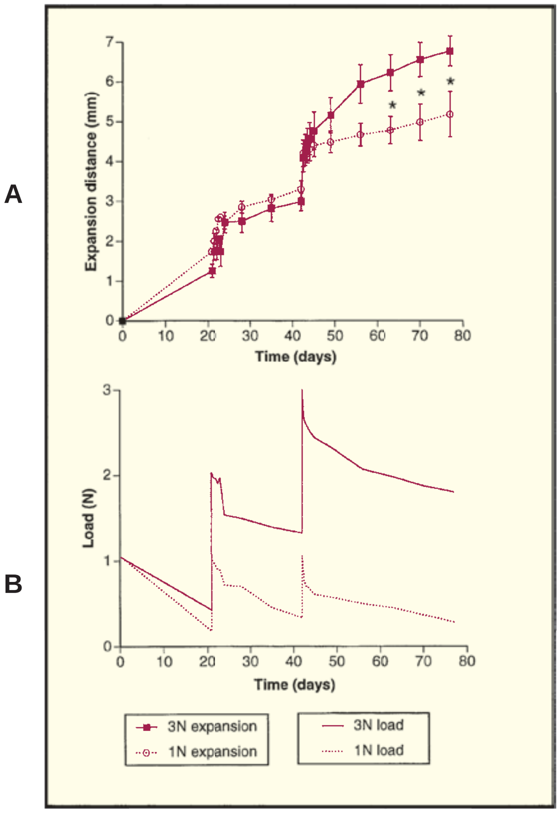


FIGURE 10-44 **A,** Sutural expansion measured as an increase in the distance between implants. The slope of this curve is the rate of sutural expansion; 3 N is significantly greater than 1 N at these time points ($p < .05$). **B,** Load on the suture as a function of time. Load was calculated using the formula $F = kx$, where k is the spring constant and x is the distance between implants. As sutural expansion occurs, force decays. Loads were placed at day 0 and adjusted at days 21 and 42. *(From Parr JA, et al: Sutural expansion using rigidly integrated endosseous implants: an experimental study in rabbits,* Angle Orthod *67(4):287, 1987.)*

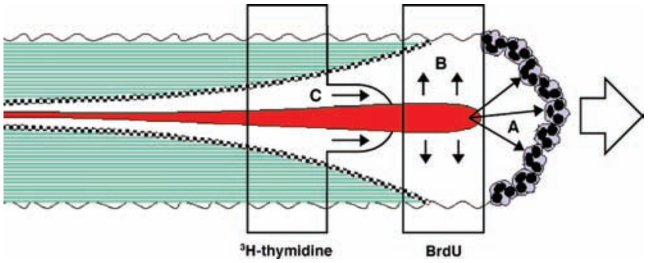


FIGURE 10-45 A cutting/filling cone in rabbit cortical bone shows the intravascular origin of osteoclasts **(A).** The perivascular proliferation and migration away for the perivascular surface **(B)** is demonstrated by bromodeoxyuridine (BrdU) labeling and nuclear volume morphometry. A sequence of ^{3}H-thymidine labels from 2 to 72 hours before sacrifice and nuclear morphometric analysis revealed migration of proliferating perivascular cells in the direction of vascular invasion **(C).** These data demonstrate the perivascular origin of osteoblasts in evolving secondary osteons. *(From Sim Y: Cell kinetics of osteoblast histogenesis in evolving rabbit secondary haversian systems using a double labeling technique with 3H-thymidine, and bromodeoxyuridine, PhD thesis, Indianapolis, 1995, Indiana University, School of Dentistry.)*

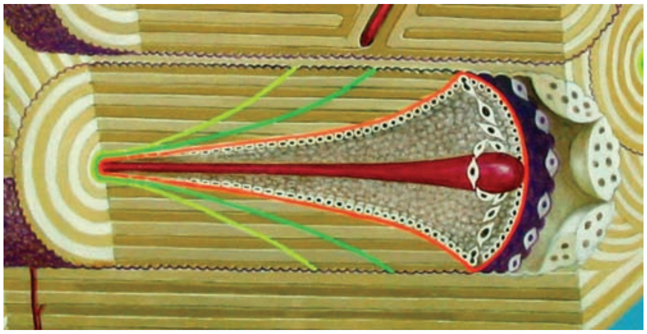


FIGURE 10-46 An evolving secondary osteon, moving to the right, shows a head of multinucleated osteoclasts (*right*), followed by a layer of mononuclear cells secreting cement substance (*blue*) to cover the scalloped resorption arrest line. The perivascular osteogenic cells proliferate and differentiate to osteoblasts, which form the new secondary osteon. Three sequential colored bone labels (*yellow, green,* and *orange*) allow the calculation of the velocity of the cutting/filling cone through cortical bone.

biomechanics studies have failed to demonstrate the advantage of expanding the papate at the same time to enhance the sagittal response.[97] Determining bone age from hand-wrist films radiographic analysis is effective for screening patients most likely to have a positive response to maxillary protraction.[98] Recently, miniplates for anchorage of intermaxillary elastics, have proved to be very effective for changing detrimental growth patterns.[99]

DISTRACTION OSTEOGENESIS

Distraction osteogenesis (DO) is a surgical procedure for reconstructing skeletal deformities of the skeleton, jaws, and alveolar processes. A corticotomy (osteotomy) divides the bone into segments, or if there is an intervening suture or PDL, the bone resisting movement is removed. A surgically assisted RPE is the most common distraction procedure used in orthodontics. Distraction of the PDL is a method for achieving rapid tooth movement,[100] but the method is too invasive for routine clinical procedures.

For DO of the maxilla, mandible, and alveolar process, the osseous segments are progressively moved apart generating new bone in the defect. The desired position of the segments is achieved in the distraction phase. The segments are then retained, allowing the gap to fuse and the newly generated bone remodels into a more mature structure (consolidation phase). A particular advantage of distraction osteogenesis is the simultaneous increase in length and volume of the investing soft tissues. This variation of the bone lengthening procedure, introduced to orthopaedic surgery by Ilizerov to lengthen limbs,[101] is now used extensively by reconstructive plastic and maxillofacial surgeons for the correction of micrognathia, midface deficiencies, and orbital anomalies in patients with craniofacial deformities. Although the procedure has been used effectively for some mandibular problems,[102] it has been problematic in some patients.[103] DO is widely used for maxillary deficiencies, for which favorable follow-up has been reported.[104] Surgically assisted protraction of the maxilla is an effective procedure, particularly in patients with craniofacial anomalies.[105] When all the bony attachments are cut for a structure like the maxilla, it is free to move in any direction dictated by the applied biomechanics.[106] Much like a suture, the osseous margins can resorb if exposed to compression, or become bone-forming surfaces when exposed to tension. Rigid external distraction has evolved as a superior to face mask for controlling the protraction and vertical position of the maxilla.[107] Mini-implants and mini-screws have proved to be effective for controlling osteotomy segments under some circumstances.[108]

New bone can be generated in the alveolar process, and teeth can be moved into it.[109] This method can be used for rapid retraction of canines or correction of tooth size–to–arch length discrepancies.[110]

ORTHODONTIC TOOTH MOVEMENT

Figure 10-47 illustrates a typical tooth movement response after application of a moderate, continuous load (0.2 to 0.5 N, or about 20 to 50 g). The orthodontic response is divided into three elements of tooth displacement: initial strain, lag phase, and progressive tooth movement. Initial strain of 0.4 to 0.9 mm occurs in about 1 week[20,111,112] because of PDL displacement (strain), bone strain, and extrusion (Figure 10-48). The initial deformation response varies according to the width of the PDL, root length, anatomic configuration, force magnitude, occlusion, and periodontal health. Initial tooth displacement occurs within seconds,[112–114] but actual compression of the PDL requires 1 to 3 hours (Figure 10-48).

Unfortunately, no studies have used a broad range of invasive and noninvasive techniques to define completely the fluid and solid mechanics associated with initiating and sustaining tooth movement. Figure 10-47 is an attempt to unify a broad range of data. The fluid mechanics of root displacement in the PDL probably accounts for about 0.3 mm of crown movement.[115] Assuming an average anatomic configuration and bone strain of 1% (about 40% of ultimate strength) or less,[28] distortion of mineralized tissue caused by bending and creep[29,55] probably accounts for about another 0.3 mm of the initial movement (see Chapters 5 and 7).[115]

Occlusal Trauma and Root Resorption

Extrusion in response to a horizontal load may be a component of initial displacement,[113] depending on the direction of the force, the point of application, and the axial inclination of the root. However, varying amounts of extrusion can be expected because of the inclined plane effect of the root apex being compressed against

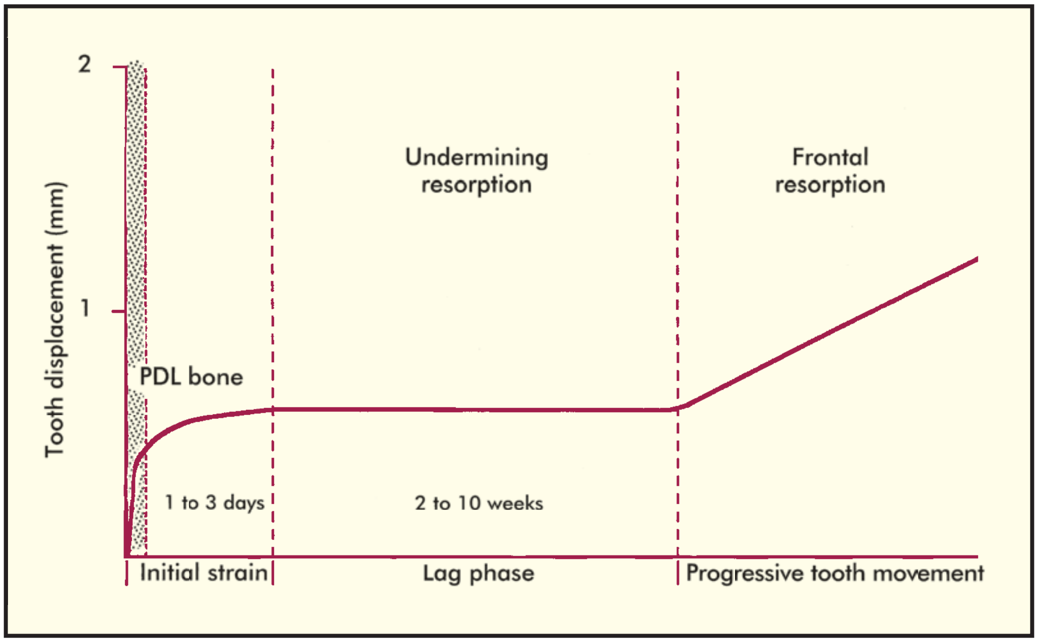


FIGURE 10-47 After application of a moderate orthodontic load (0.2 to 0.5 N, or about 20 to 50 *g*), tooth displacement is divided into three phases: (*1*) initial strain for 1 to 3 days in the periodontal ligament (*PDL*) and supporting bone; (*2*) a variable lag phase, in which undermining resorption removes bone adjacent to crushed areas in the PDL; and (*3*) progressive tooth movement when frontal resorption in the PDL limits the rate of orthodontic correction.

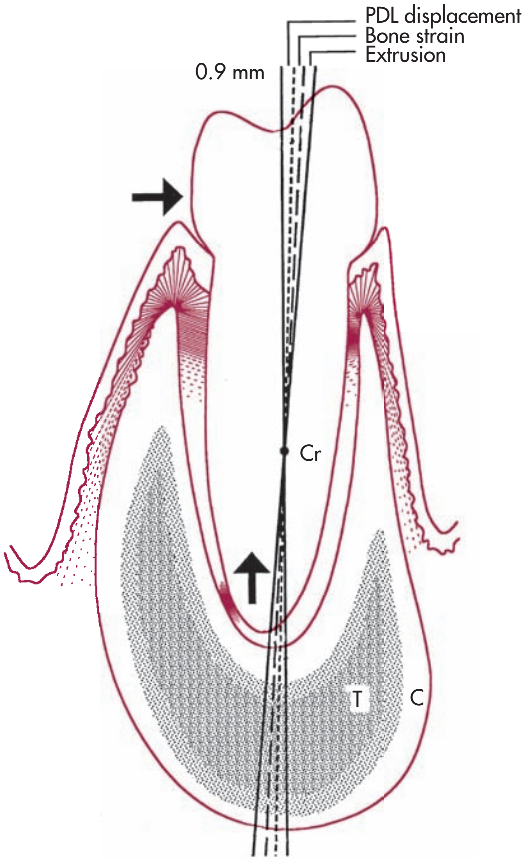


FIGURE 10-48 Initial displacement (1 to 3 days) of a tooth exposed to a tipping (horizontal) load usually is about 0.5 mm but may be as much as 0.9 mm for teeth that are slightly mobile, periodontally compromised, or heavily loaded. The three components are (*1*) displacement of the root in the periodontal ligament (*PDL*); (*2*) bone strain caused by bending and creep; and (*3*) extrusion caused by the inclined plane effect of the tooth root pressing against a tapered alveolus. *(From Roberts WE, et al:* Bone biodynamics in orthodontic and orthopedic treatment: craniofacial growth series, *vol 27, Ann Arbor, 1991, University of Michigan Press.)*

the alveolus (see Figure 10-48). The tendency toward extrusion and enhanced horizontal displacement during tooth movement varies directly with force magnitude and periodontal compromise of the dentoalveolar fibers at the alveolar crest. Extrusion and occlusal prematurities are distinct possibilities, particularly for periodontally compromised teeth, and these conditions depend on the vertical constraint of a clinically applied load (see Figure 10-34, *A*). If occlusal prematurity is a chronic periodontal trauma, root resorption may result because of catabolic cytokines in the PDL[116] or because of fatigue failure (see Figure 10-34, *B*).

Remodeling of Bones and Teeth

Remodeling is the physiologic term for internal turnover of a mineralized tissue, without a change in its overall form. It is a coupled sequence of catabolic (resorptive) and anabolic (osteogenic) events to support calcium homeostasis and repair (renew) aged or damaged mineralized tissue. Histologic studies indicate that both bones and teeth remodel. Remodeling mechanisms are involved in growth, functional loading, tooth movement, root resorption, and the systemic health of patients. In contrast, cortical bone remodeling is via cutting/filling cones, which Harold Frost deemed bone multicellular units (BMUs). Trabecular bone remodeling is accomplished by hemicutting/filling cones (surface resorption cavities that fill with new bone), also referred to as BMUs. Histologic studies in multiple species have demonstrated that root resorption cavities are usually repaired (filled) with secondary cementum. In effect, this is "remodeling" of the root of a tooth. The evolution of bone remodeling concepts, as originally defined by Frost, are important for understanding craniofacial growth and the skeletal adaptation associated with orthodontics and dentofacial orthopedics.[117]

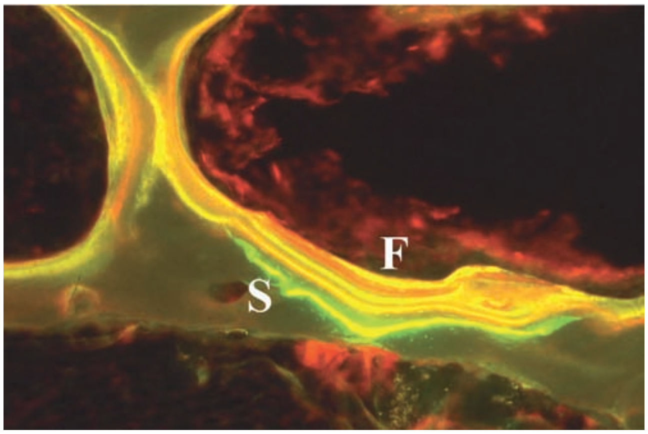


FIGURE 10-49 Trabecular bone remodeling in the vertebrae in a rat: multiple fluorochrome labels demonstrate bone formation (*F*) over a scalloped resorption arrest line (*S*). *[From Roberts WE, Roberts JA, Epker BN, et al: Remodeling of mineralized tissues, part I: the Frost legacy,* Semin Orthod *12(4):216–237, 2006.]*

Trabecular Bone Remodeling. Figure 10-49 illustrates the bone labeling that occurs in the trabeculae of rat vertebrae. This is a remodeling process because the new bone is laid down on a scalloped resorption reversal line. The latter is the principal distinction between micromodeling and remodeling. Remodeling of trabecular bone is under mechanical and hormonal control. Corticosteroids have long been associated with metaphyseal growth[118] and osteopenia of trabecular bone.[119] Although the catabolic effects of parathyroid hormone has been known for decades, its anabolic effect has been exploited more recently.[120,121]

For a detailed discussion of calcium homeostasis and trabecular bone remodeling, from an orthodontics perspective, see Roberts.[122] A schematic drawing (Figure 10-50, *A*) of adult trabecular bone illustrates the pattern

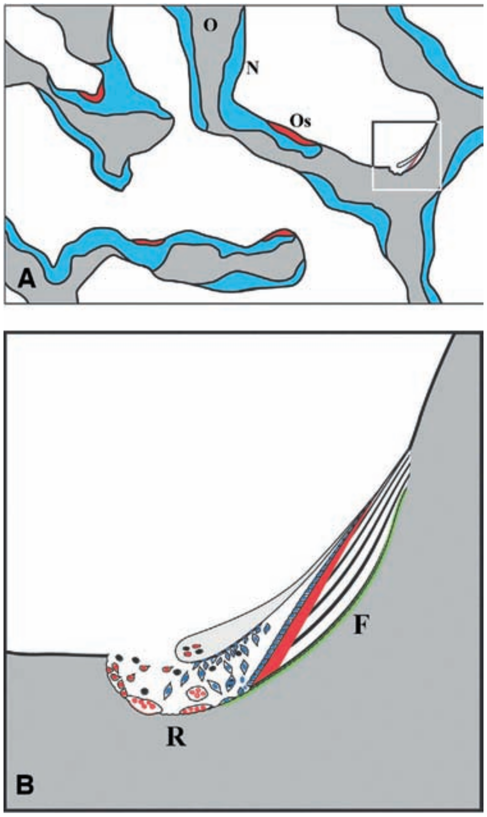


FIGURE 10-50 **A,** A schematic drawing of trabecular bone remodeling over a 1-year interval shows the pattern of new bone formation (*N*) relative to old bone (*O*) and osteoid seams (*Os*). The *box* marks an area of active trabecular resorption, which is magnified in the accompanying figure **(B). B,** A detailed drawing of an active remodeling site (magnified from **A**) shows a hemicutting/filling cone with a similar perivascular array of resorptive (*R*) and formative (*F*) cells as shown for cortical bone remodeling. The osteoclastic and osteoblastic cell lines are *red* and *blue*, respectively. An unmineralized osteoid seam (*solid red line*) marks the bone forming surface. *(From Roberts WE, Roberts JA, Epker BN, et al: Remodeling of mineralized tissues, part I: the Frost legacy,* Semin Orthod *12(4):216–237, 2006.)*

FIGURE 10-51 In 1980, Dr. Kaare Reitan is shown at the University of Oslo at the time when he shared some of his human histology slides with Dr. Roberts. *(From Roberts WE, Roberts JA, Epker BN, et al: Remodeling of mineralized tissues, part I: the Frost legacy,* Semin Orthod *12(4):216–237, 2006.)*

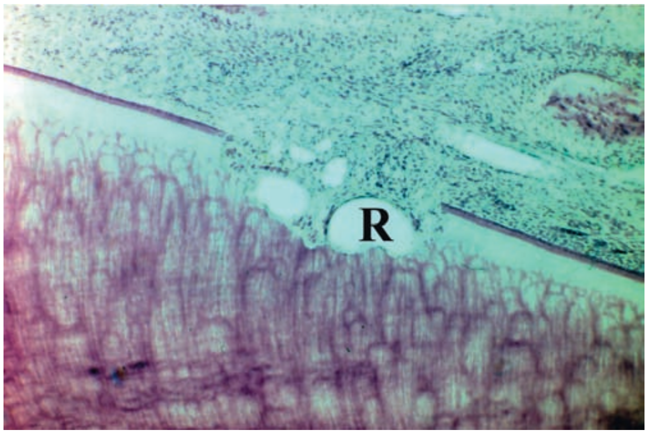


FIGURE 10-52 Lateral root resorption (*R*) on an unstimulated, control human premolar (Dr. Reitan). These lesions are usually self-limiting and fill with cellular cementum via a process with is histologically similar to the hemi-cutting/filling cone of trabecular bone remodeling (see Figure 10-50, *B*). *(From Roberts WE, Roberts JA, Epker BN, et al: Remodeling of mineralized tissues, part I: the Frost legacy,* Semin Orthod *12(4):216–237, 2006.)*

of turnover associated with continuous remodeling to support calcium homeostasis. An individual remodeling site is shown in Figure 10-50, *B*. The A→R→F process is similar to the cutting/filling cones of cortical bone remodeling (see Figures 10-22, 10-45, and 10-48). The trabecular bone remodeling mechanism is essentially a hemicutting/filling cone.[122]

Root Remodeling. Teeth are composed of mineralized tissues derived from epithelium and mesoderm (mesenchyme).[123] Enamel, dentin, and acellular cementum are unique, genetically defined tissues that are formed or induced by epithelial tissue. Although all three mineralized tissues are subject to fatigue damage over a lifetime, none has a remodeling (turnover) capability. Enamel, dentin, and acellular cementum may be destroyed by physical or biological mechanisms, but none of these specialized dental tissues can be reformed after tooth development is complete. Cellular cementum is the adaptation and repair tissue that helps maintain dental function over a lifetime. Although cellular cementum may present a histologic appearance similar to bone, it is a distinct tissue both structurally and chemically. Dr. Kaare Reitan's (Figure 10-51) histologic studies of human teeth demonstrated that incipient (Figure 10-52) and advanced root resorption lesions (Figure 10-53) are similar to the resorptive phase of the remodeling cycle in trabecular bone. Lateral root resorption lesions are common when teeth are moved orthodontically.[122]

Similar to trabecular bone remodeling, the resorption cavities are usually self-limiting and subsequently fill with secondary cellular cementum. It has long been

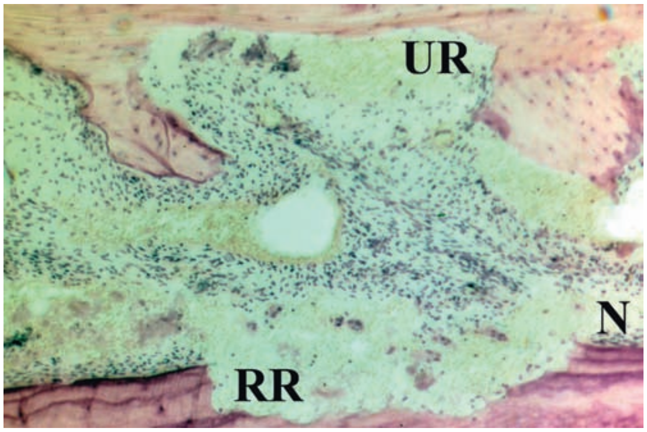


FIGURE 10-53 Extensive lateral root resorption (*RR*) and undermining resorption (*UR*), just to the left of an area of PDL necrosis (*N*), is associated with the lag phase of tooth movement. This section of human tissue was provided by Dr. Reitan. *(From Roberts WE, Roberts JA, Epker BN, et al: Remodeling of mineralized tissues, part I: the Frost legacy,* Semin Orthod *12(4):216–237, 2006.)*

known that teeth experience episodes of root resorption followed by cementum repair. It is proposed that this is a mechanism for renewing damaged root structure that is similar to the surface remodeling of trabecular bone. Loss of control of the self-limiting resorption process is expressed pathologically as external resorption, which often results in loss of the tooth. Orthodontics and dentofacial orthopedics results in a sharp increase in the numbers of root resorption sites, which subsequently repair with cellular cementum (coupled A→R→F sequence). [124] The reversal process requires laying down cementing substance on previously resorbed surface to prepare it for apposition of cellular cementum.[125] Furthermore, recovery of a functional PDL, following bisphosphonate-induced ankylosis, involves a period of root resorption followed by cementum repair, [126] which is similar to the A→R→F sequence of bone remodeling. The latter is the principal healing response to internal bone injury such as the placement of an endosseous implant. As previously proposed by Reitan, interrupted forces tend to result in less net root resorption, because resorption cavities tend to repair with cellular cementum in 5 to 8 weeks.[127,128] Since Reitan noted that interrupted forces result in less net root resorption, because resorbing sites have an opportunity to fill with cellular cementum before subsequent reactivation, perhaps long-acting forces, such as NiTi wires may not be optimal for achieving minimal loss of tooth structure during orthodontic therapy. The control and expression of root resorption/cementum repair is quite similar to bone remodeling because it: (1) is an A→R→F sequence, (2) requires a layer of cementing substance before reversal from R→F, and (3) is induced by wounding or increased loads. The similarities between bone remodeling and root resorption are striking: Kimura and coworkers[129] concluded that the "odontoclasts" of root resorption have an intravascular origin similar to the osteoclasts of bone remodeling. Considering all available evidence, it appears that root resorption is a portion of the turnover process to replace damaged root structure. It follows that root resorption followed by cementum repair is a form of root remodeling akin to bone turnover. From a clinical perspective, it is important for orthodontists to consider mechanics and retention procedures that provide for adequate periods of atraumatic rest to allow resorbing sites to refill with cellular cementum.[128] Continuous forces, particularly if they are associated with traumatic occlusion, may result in permanent loss of root structure[122] if multiple sites of root resorption communicate before the initiation of their respective cementum repair phases. Remodeling of mineralized tissues is an obligatory physiologic process for maintaining the strength and structural integrity of bones and roots of teeth. It is a coupled ARF sequence that was first described by the late Harold Frost, to whom this article is dedicated. Damaged hard tissue (bone, cementum, or dentin) is resorbed and replaced by new mineralized tissue (lamellar bone or cellular cementum). An accurate understanding of bone remodeling mechanisms is essential to appreciating the etiology of malocclusion and the pathophysiologic response to orthodontic and dentofacial orthopedic therapy.

Induction of the Tooth Movement Response

Progressive displacement of the tooth relative to its osseous support stops in about 1 week (see Figure 10-47), apparently because of areas of PDL necrosis (hyalinization). This lag phase varies considerably; it usually lasts 2 to 3 weeks but may be as long as 10 weeks.[111] Clinical experience and histologic studies [111,115] suggest that the duration of the lag phase is related directly to the patient's age, the density of the alveolar bone, and the extent of PDL necrotic zones. After undermining resorption restores vitality to the necrotic areas of the PDL, tooth movement enters the secondary,[111,112] or progressive, tooth movement phase (see Figure 10-47). Frontal resorption (modeling) in the PDL and initial remodeling events (resorption cavities) in cortical bone ahead of the advancing tooth (see Figure 10-23 *A*) allow for progressive tooth movement at a relatively rapid rate.

Gene expression during the initiation of tooth movement has recently been reviewed.[130] Low energy laser irradiation enhances the initiation and velocity of tooth movement by increasing the expressions of matrix metalloproteinase-9, cathepsin K, and $\alpha_v\beta_3$ integrin.[131]

The mechanism of sustained tooth movement is a coordinated array of bone resorption and formation events (see Figure 10-23, *A*). Both fundamental mechanisms of osseous adaptation, modeling and remodeling, are involved.[132] A modeling response is noted in the alveolus; bone resorption occurs where the PDL is compressed (in the direction of movement), and bone formation maintains the normal width of the trailing PDL. By means of this coordinated series of surface modeling events, the alveolus drifts in the direction of tooth movement. The modeling events of tooth movement commonly are referred to as areas of compression and tension within the PDL.[111,112] For small amounts of tooth movement (less than 1 mm) over 1 or 2 months, PDL modeling probably is the predominant mechanism of tooth movement. However, when teeth are moved greater distances over longer periods, the PDL response is supplemented by alveolar bone remodeling and periosteal modeling (Figures 10-54 and 10-55).

Remodeling of dense alveolar bone (Figure 10-54) may enhance the rate of tooth movement[115] and replace the less mature osseous tissue formed by rapid PDL osteogenesis (Figure 10-55). Resorption cavities ahead of the moving tooth reduce the density of cortical bone (Figure 10-54). These intraosseous cavities are the initial remodeling events that occur during the first month of the remodeling cycle (see Figure 10-20). With progressive tooth movement, it appears that these resorption cavities are truncated remodeling events.[115] Continuous force[133,134] or reactivation at about 1-month intervals is expected to yield the maximal rate of tooth movement through cortical bone. The remodeling-dependent concept of long-range tooth movement has important clinical implications. Efficient mechanics and regular reactivations at about 4-week intervals long have been associated with optimal rates of tooth movement.[115] However, breakage, distortion of appliances, and appointment failures substantially increase treatment time. One reason for slow tooth movement in uncooperative patients may be the tendency for resorption cavities initiated by orthodontic activation to complete the remodeling cycle by refilling with new bone if appropriate mechanics are not maintained. Repeatedly reinitiating force after periods of periodontal recovery requires one startup period after the other (see Figure 10-47) to reestablish the modeling and remodeling mechanisms to move a tooth through dense cortical bone.

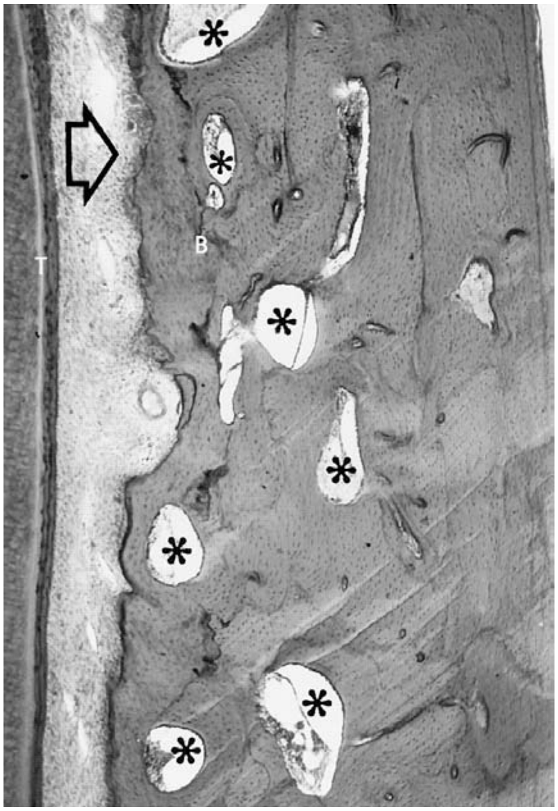


FIGURE 10-54 Demineralized histologic section of human periodontium reveals the modeling and remodeling mechanisms of progressive tooth movement through dense cortical bone *(B).* A tooth (*T*) is moving in the direction of the *large arrow*. The rate of translation is enhanced by frontal resorption in the periodontal ligament communicating with the extensive resorption cavities (*) created by initial remodeling events (cutting cones). By this mechanism, teeth move through dense cortical bone at a rate of about 0.3 mm a month (×25). *(From Roberts WE, et al:* Bone biodynamics in orthodontic and orthopedic treatment: craniofacial growth series, *vol 27, Ann Arbor, 1991, University of Michigan Press.)*

Secondary osteons are formed in new cortical bone trailing a moving tooth (see Figure 10-55). The major modeling and remodeling events associated with sustained buccal movement (controlled tipping) of a lower premolar are summarized in Figure 10-56. The efficiency of bone resorption is the rate-limiting factor in tooth movement. Bone is removed ahead of the moving tooth by two mechanisms: frontal resorption at the PDL interface and initial remodeling events (resorption cavities) in the cortical plate. In addition to PDL modeling of the alveolus (bone resorption in the area of pressure and bone formation in the area of tension), Figure 10-56 shows surface modeling on periosteal and endosteal surfaces. These coordinated modeling events maintain the structural relationship of the alveolar process as the tooth moves.[61]

PERIODONTAL LIGAMENT RESPONSE

Within 1 minute after application of a continuous orthodontic load to a rat maxillary first molar, a more negative electrical potential is noted where the PDL is widened and a more positive signal where it is compressed (Figure 10-57). These bioelectric changes are not piezoelectric signals but are probably streaming potentials.[22] Changes in electrical potential may drive the PDL osteogenic and osteoclastic responses or may be merely physical manifestations of the intense cellular activities (ion flux across cell membranes) triggered by orthodontic stimuli.[17] Coordination of cellular reactions in the PDL to changes in electrical potential is a prime area for future investigation.

Application of orthodontic force initiates a cascade of cellular proliferation and differentiation events in the

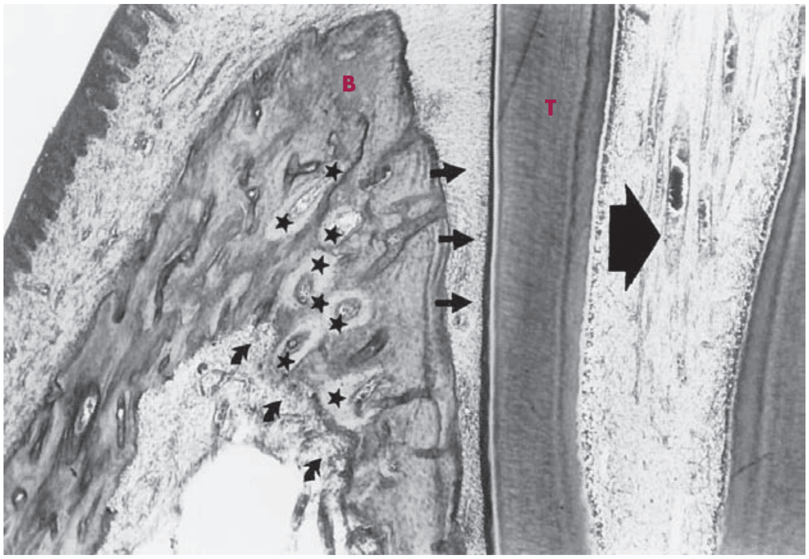


FIGURE 10-55 A demineralized histologic section of human periodontium documents the bone modeling and remodeling aspects of alveolar bone (*B*) drift in the direction of tooth (*T*) movement (*large black arrow*). Three major aspects of bone modeling are noted: (1) new bone formation in the periodontal ligament (*small horizontal arrows*); (*2*) periosteal resorption on the lingual alveolar bone surface (*left*); and (*3*) endosteal resorption (in the direction of the curved arrows) to maintain the cortical thickness of the alveolar crest as it drifts to the right. Bone remodeling replaces relatively immature bone with new secondary osteons (*stars*) (×25). *(From Roberts WE, et al:* Bone biodynamics in orthodontic and orthopedic treatment: craniofacial growth series, *vol 27, Ann Arbor, 1991, University of Michigan Press.)*

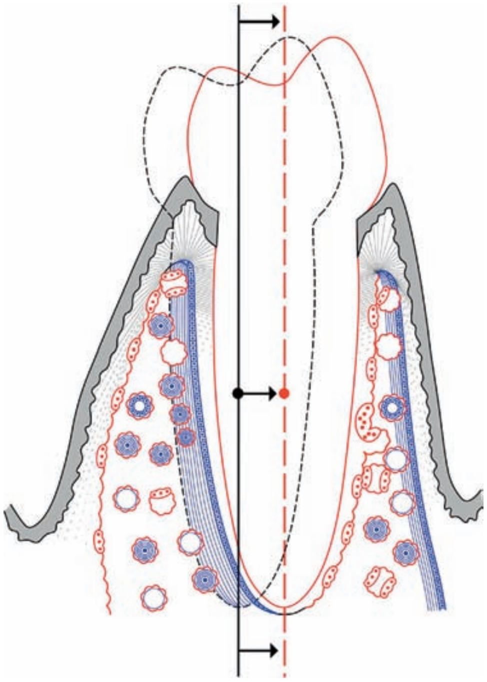


FIGURE 10-56 A schematic diagram shows the bone physiology associated with translation of a tooth. Note that there is a coordinated bone modeling and remodeling response leading and trailing the moving tooth. This mechanism allows a tooth to move relative to basilar bone while maintaining a normal functional relationship with its periodontium. Osteoclastic and osteoblastic activities are shown in *red* and *blue,* respectively. *(From Roberts WE, Roberts JA, Epker BN, et al: Remodeling of mineralized tissues, part I: the Frost legacy,* Semin Orthod *12(4):216–237, 2006.)*

PDL. Maximal compression of the PDL occurs in 1 to 3 hours (Figure 10-58), a time frame consistent with most clinical estimates for initial displacement after application of an orthodontic load (see Figure 10-47). The postactivation sequence of about 6 hours for the initiation of tooth movement has been confirmed with a nitric oxide synthetase assessment in rat PDL.[135]

A variety of nervous, immune, and endocrine system responses, as well as local cytokines and intracellular messages, have been implicated in the osseous adaptive reaction as the root of the tooth is displaced.[136] These localized agents probably are mediators of the often painful transient inflammatory events noted during the initiation of the orthodontic reaction. The role of local cytokines in the sustained bone modeling and remodeling events of tooth movement is unknown. However, prostaglandins are thought to be important factors in the control of mechanically mediated bone adaptation.[93,116,137,138]

Comparing control rat PDL (Figure 10-59, *A*) with orthodontically stimulated PDL (Figure 10-59, *B*) helps define the biological mechanisms for mechanically induced bone formation and resorption. The specificity of bone resorbing and forming sites is dictated by the physics of the applied force system.[133] Although the PDL histologic changes and cell kinetics associated with orthodontically induced osteoclasis and osteogenesis are well defined,[15,20,111,112,115,123,125,129,139,140] the cellular mechanisms controlling tooth movement are less clear. An

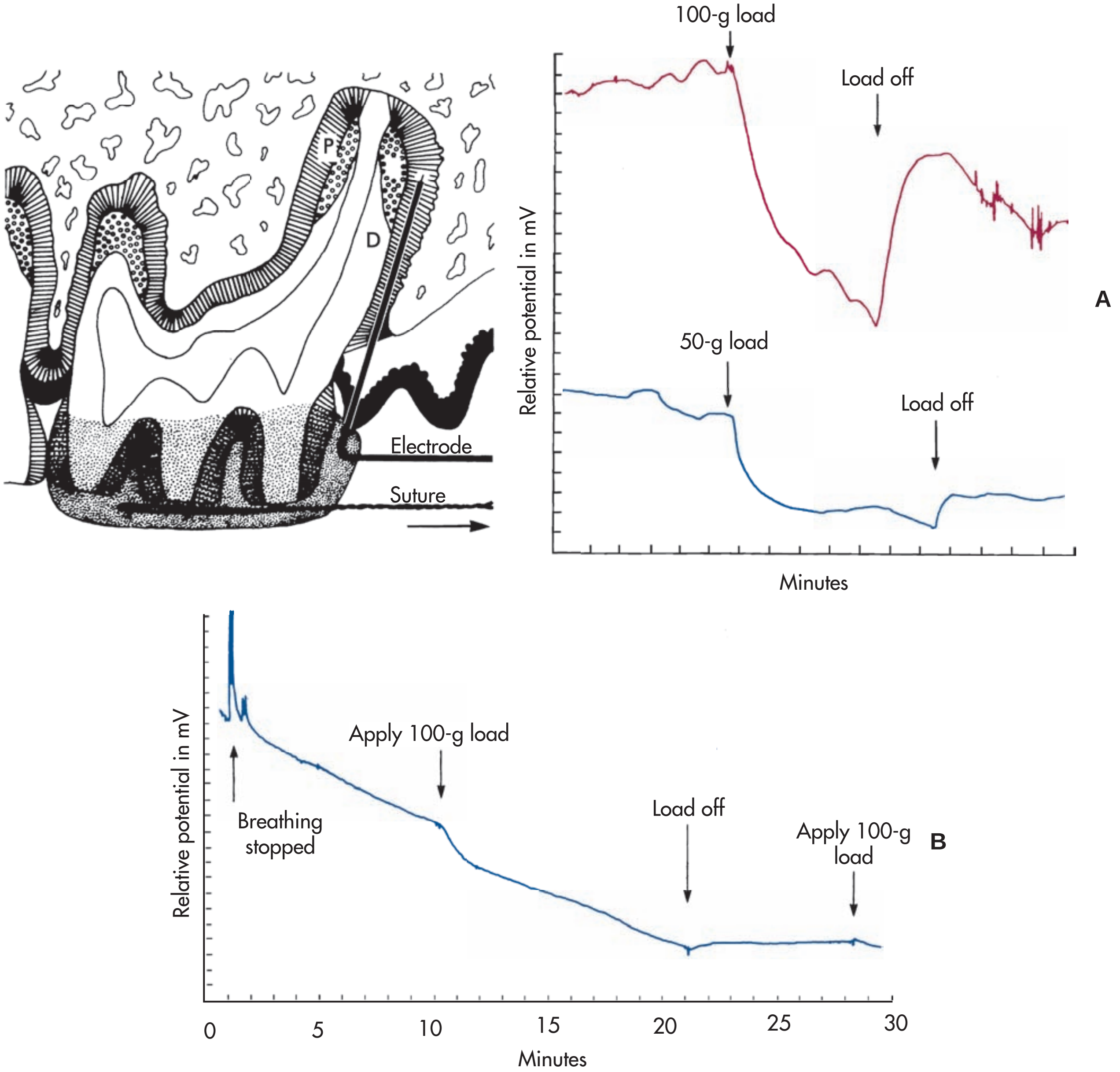


FIGURE 10-57 **A,** A tungsten microelectrode is inserted on the mesial aspect of a rat maxillary first molar and stabilized to the tooth with composite resin. An orthodontic load of 50 to 100 *g* (about 0.5 to 1 N) applied with a traction suture results in a more negative electrical potential in the periodontal ligament, where new bone formation occurs. **B,** Similar measurements of electrical potential were performed in orthodontically stimulated periodontal ligament of a rat terminated with an overdose of anesthetic. The electrical response was lost 20 minutes after breathing stopped. *(From Roberts WE, et al: Change in electrical potential within periodontal ligament of a tooth subjected to osteogenic loading. In Dixon A, Sarnat B, editors:* Factors and mechanisms influencing bone growth, *New York, 1982, Allan R Liss.)*

interaction of metabolic, biomechanical, bioelectric, and biochemical factors has been implicated.[17,20,115,116,141] The challenge is to determine the sequence cybernetic events.[115]

Minimal proliferative activity is noted in areas of the PDL where bone resorption predominates. However, an intense proliferative response is noted in the PDL where new is destined to form.[14,15,139,140,142] For the first 12 hours after initiation of orthodontic stimulus, a modest, nonspecific increase of cells into mitotic and DNA S phases occurs throughout the PDL (Figure 10-60, *A*). After 16 hours a specific osteogenic response is noted in the area of the PDL where new bone formation will begin (Figure 10-60, *B*). More than half of the fibroblast-like PDL cells in the widened area of the PDL enter the DNA S phase of the cell cycle[143] and subsequently

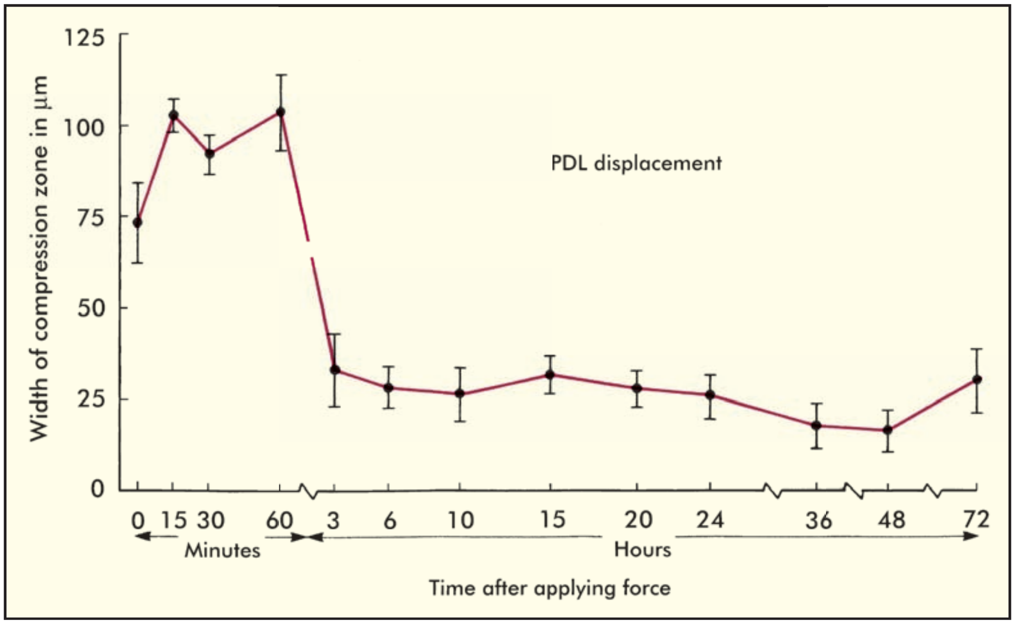


FIGURE 10-58 Initial displacement of the mesial root of rat maxillary first molars in the periodontal ligament (*PDL*) space is assessed by measuring the width of the maximal compression zone. This method is an index of periodontal ligament displacement that is relatively independent of bone deformation. Note the resistance to compression during the first hour, followed by maximal compression at 3 hours, creating necrotic areas where undermining resorption will occur.

divide.[115,144] Preosteoblasts then migrate from throughout the PDL to the alveolar bone surface (Figure 10-61),[12] form osteoblasts, and initiate new bone formation in about 40 to 48 hours.[14,115]

The orthodontic response in the PDL is an effective experimental model for determining the physiologic mechanisms of mechanically induced bone modeling. Orthodontic stimulation of rat maxillary molars has been particularly useful for initiating a defined osteogenic reaction within the PDL on the mesial aspect of the mesial root (see Figure 10-59, *B*). Using the finite element modeling method, one can calculate stresses in the tissue down to the cellular level. Tissue complexity and the diverse range of mechanical properties make orthodontically stressed periodontium a relatively challenging application of the finite element modeling method. The model simulates the experimental tipping of a rat maxillary first molar (Figure 10-62, *A*). Osteogenesis was concluded to occur where maximal principal stress was elevated in the PDL (Figure 10-62, *B*). Bone resorption began where peaks in minimal principal stress, maximal shear, and strain energy density developed.[18]

OSTEOBLAST HISTOGENESIS AND BONE FORMATION

Osteoblasts are derived from paravascular connective tissue cells (Figure 10-63). The less differentiated precursor and committed osteoprogenitor cells are associated closely with blood vessels. Their progeny (preosteoblasts) migrate away from the blood vessels. The major rate-limiting step in the histogenesis sequence occurs as the cells move through an area of low cell density about 30 mm from the nearest blood vessel.[91] The osteoblast histogenesis sequence (Figure 10-64) was determined by in situ morphologic assessment of three distinct events in cell physiology: (1) DNA S phase, (2) mitosis, and (3) the increase in nuclear volume (A′ → C shift) that accomplishes differentiation to a preosteoblast.[132]

Careful cell kinetic analysis of orthodontically induced osteogenesis[16] demonstrated that the initial mechanically mediated step in osteoblast histogenesis is differentiation of preosteoblasts from less differentiated precursor cells (Figure 10-65). Subsequent studies further classified the less differentiated precursor cells into committed osteoprogenitor (A′) cells and self-perpetuating precursor (A) cells.[144] The morphologic marker for this key step in osteoblast differentiation (change in genomic expression) is an increase in nuclear volume—preosteoblasts have larger nuclei than their precursors. The finite element analysis studies[18] suggest that the crucial mechanical parameter initiating the rate-limiting step in the osteogenic response probably is maximal principal stress in the PDL (see Figure 10-62). Cell kinetic analyses (e.g., DNA labeling and nuclear volume morphometry) coordinated with finite element modeling of identical specimens are powerful methods of elucidating the biomechanical control of bone cells in vivo.

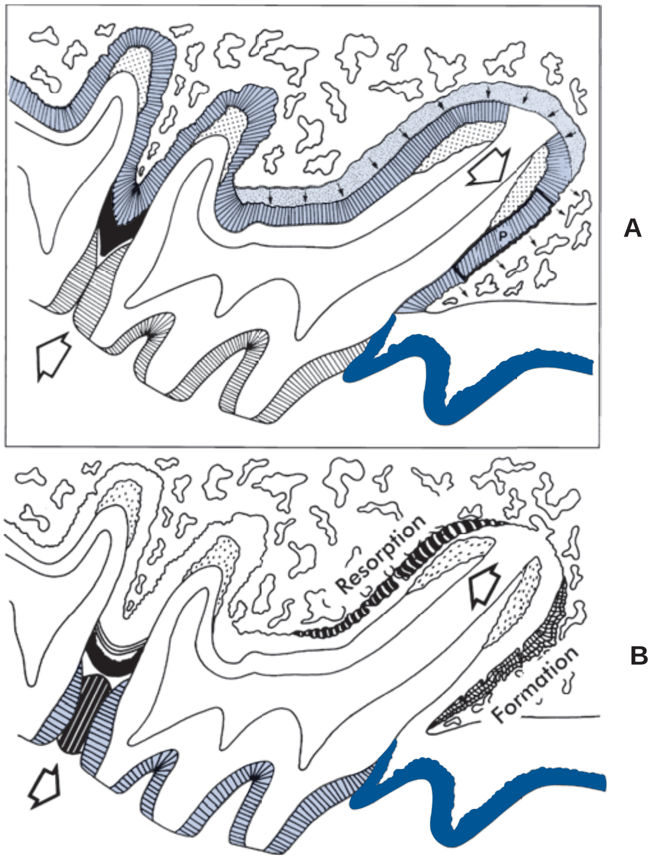


FIGURE 10-59 **A,** Physiologic drift for the mesial root of a rat maxillary first molar involves a relative tipping of the tooth in the direction of the large arrows. Net resorption occurs adjacent to the area of the periodontal ligament (*P*) marked with the *bold outline*. Bone formation is noted along the periodontal ligament adjacent to the stippled area. **B,** Inserting a Latex elastic between the first and second molars reverses the direction of tooth movement, resulting in resorption on a previously bone-forming surface (*above*) and vice versa (*below*). (***A,*** *From Roberts WE, Morey ER: Proliferation and differentiation sequence of osteoblast histogenesis under physiological conditions in rat periodontal ligament,* Am J Anat *174:105, 1985;* ***B,*** *from Roberts WE: Advanced techniques for quantitative bone cell kinetics and cell population dynamics. In Jaworski KFG, editor:* Proceedings of the First Workshop on Bone Morphometry, *Ottawa, 1976, University of Ottawa Press.)*

Orthodontically induced osteogenesis is associated with elevated stress in the PDL. Orthodontically induced bone resorption to allow tooth movement is associated with elevated stress in alveolar bone (lamina dura) when maximal compression of the PDL occurs.[18]

Figure 10-66 shows the current sequence for kinetic control of orthodontically induced osteogenesis. The stopcock labeled *1* shows that unstimulated PDL maintains a substantial fraction of preosteoblasts (C and D cells) by restricting cell flow before mitosis of D cells. This is a block in the G2 stage of the cell cycle. With orthodontic stimulus, the stopcock is opened, preosteoblasts (C and D cells) are depleted, new C cells are formed by A′ cells, and A cells produce more A′ cells.

In an unstimulated PDL, some cells tend to be blocked at the end of the G1 and G2 periods, but most osteogenic cells are held in reserve (G0 phase) until osteogenesis is induced mechanically (Figure 10-67). Figure 10-68 shows the cell kinetic sequence associated with orthodontic induction of new bone formation: (1) the peak of new preosteoblasts (increased $A' \rightarrow C$ activation) is noted at 8 hours; (2) the maximal level of DNA synthesis is evident at about 20 hours; (3) a burst of mitotic activity is seen in about 30 hours; (4) new labeled osteoblasts progressively accumulate after about 35 hours; and (5) new bone formation is initiated about 40 to 48 hours after application of the force.[14,15] Five compartments of PDL cells have been defined in the osteoblast differentiation sequence.[144] The rate-limiting step in the differentiation of osteoblasts is the formation of preosteoblasts from committed osteoprogenitor cells. Induction of preosteoblast formation ($A' \rightarrow C$) is mediated mechanically (see Figures 10-65 and 10-66). The photoperiod (circadian rhythm) exerts a strong influence on the 60-hour proliferation and differentiation sequence. S phase, mitosis, and the $A' \rightarrow C$ shift in nuclear size have specific photoperiod preferences (Figure 10-69). The process requires five alternating 12-hour dark/light cycles (a total of 60 hours) for a G1–stage A cell to progress through the entire histogenesis sequence to form two osteoblasts. At least part of the photoperiod effect reflects varying endocrine levels during the circadian cycle. For instance, corticosteroids tend to enhance differentiation ($A' \rightarrow C$) but suppress DNA synthesis of preosteoblasts (C cells). The important point is that optimal osteoblast histogenesis under physiologic circumstances requires a normal photoperiod (Figure 10-70).[17,144] Disruption of the circadian rhythm caused by physiologic stress, traveling, or irregular sleep patterns may adversely affect the production of osteoblasts.

OSTEOCLAST RECRUITMENT AND BONE RESORPTION

Bone resorption is the limiting factor that determines the rate of tooth movement.[17,115] The removal of osseous tissue during progressive tooth movement is related directly to (1) bone porosity, (2) the remodeling rate, (3) the resorption rate, and (4) osteoclast recruitment. Porous cortical and trabecular bone allows improved access for osteoclasts. The remodeling rate is related directly to resorption cavities and the number of osteoclasts present at any time in resisting bone. The osteoclast resorption rate largely is controlled by metabolic factors, particularly PTH.[145,146] No direct evidence exists to suggest that osteoclasts are produced in the PDL or at any other bone surface. Preosteoblasts derived from the marrow enter the PDL and adjacent bone through the blood circulation.[17,115,147]

Roberts and Ferguson[17] compared the cell kinetics of metabolic and mechanical induction of PDL resorption.

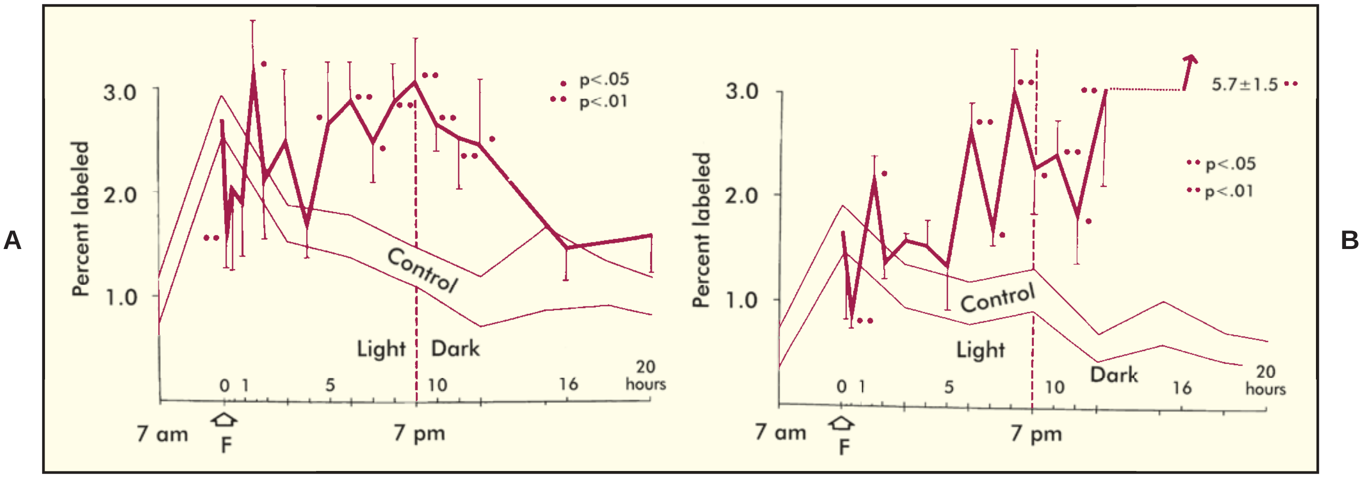


FIGURE 10-60 **A,** Compared with the normal circadian range of DNA S phase cells, orthodontic stimulus (*F*) results in a modest, nonspecific increase in S phase cells throughout the periodontal ligament. This is a mechanically induced release of G_1-blocked cells. These data are from the alveolar crest area, where no new bone formation occurs. **B,** In the midroot area, where new bone formation is induced, a similar nonspecific response is followed by a large proliferative reaction that specifically supports orthodontically induced osteogenesis. *(From Smith RK, Roberts WE: Cell kinetics of the initial response to orthodontically induced osteogenesis in rat molar periodontal ligament,* Calcif Tissue Int *30:51, 1980.)*

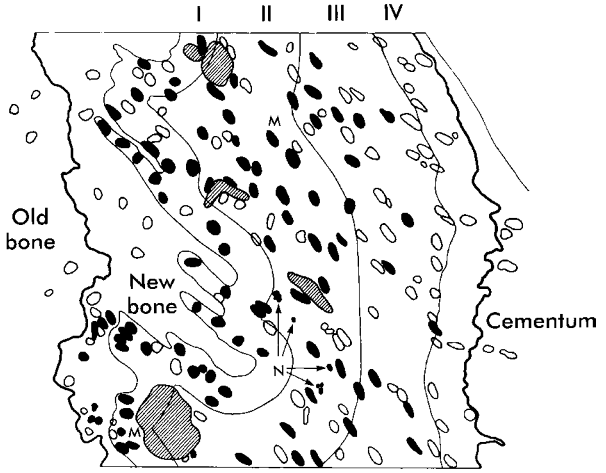


FIGURE 10-61 During the first 70 hours of orthodontically induced osteogenesis, periodontal ligament osteogenic cells migrate toward the bone surface from throughout the ligament. Cell migration patterns are tracked by repeated injection of the DNA precursor ^{3}H-thymidine. Labeled cells have black nuclei. *(From Roberts WE, Chase DC: Kinetics of cell proliferation and migration associated with orthodontically induced osteogenesis,* J Dent Res *60(2):174, 1981.)*

As shown in Figure 10-71, the number of osteoclasts per millimeter of bone surface is maximal about 9 hours after a single injection of parathyroid extract. Mechanical stimulation produces a slow but more sustained response that requires almost 50 hours to reach the same osteoclast density. Preosteoclasts are derived from the marrow by circulating promonocyte derivatives (Figure 10-72; see Chapter 5).

PTH is an established metabolic stimulus for recruiting preosteoclasts from the bloodstream.[147] The hormone produces a modest, nonspecific increase in PDL proliferation.[148] Unlike the intense cell replication associated with osteogenesis,[15,115,139] neither PTH nor orthodontically induced resorption results in elevated cell proliferation in PDL or adjacent bone. These data are consistent with the marrow origin of osteoclasts. Metabolic stimulus of osteoclastic resorption may result in tooth mobility or elevated turnover of alveolar bone. For instance, a low-calcium diet in dogs results in elevated endogenous PTH levels; the resulting high-turnover osteopenia contributes to an enhanced rate of orthodontic tooth movement[52] because of lower bone density and an elevated remodeling rate. Unfortunately, this approach is not acceptable for clinical use because of the considerable amount of systemic bone loss.

Because osteoclasts originate in the marrow, production of osteoclast precursor cells is under systemic (metabolic) and local (hematopoietic) control. The reservoir of circulating osteoclast precursors is controlled systemically. However, the localization of resorptive sites in the PDL is regulated mechanically. Metabolic stimuli such as PTH produce a relatively nonspecific resorption response along previously resorbing surfaces.[148] Mechanical induction is a specific response that occurs only in the direction of tooth movement. The current challenge is to understand the mechanical and biological components of the resorptive mechanism. Orthodontic force that results in elevated stress in the osseous cortex is followed by a specific resorptive response.[18] Prostaglandins, interleukins, neurosecretory agents, and growth factors may

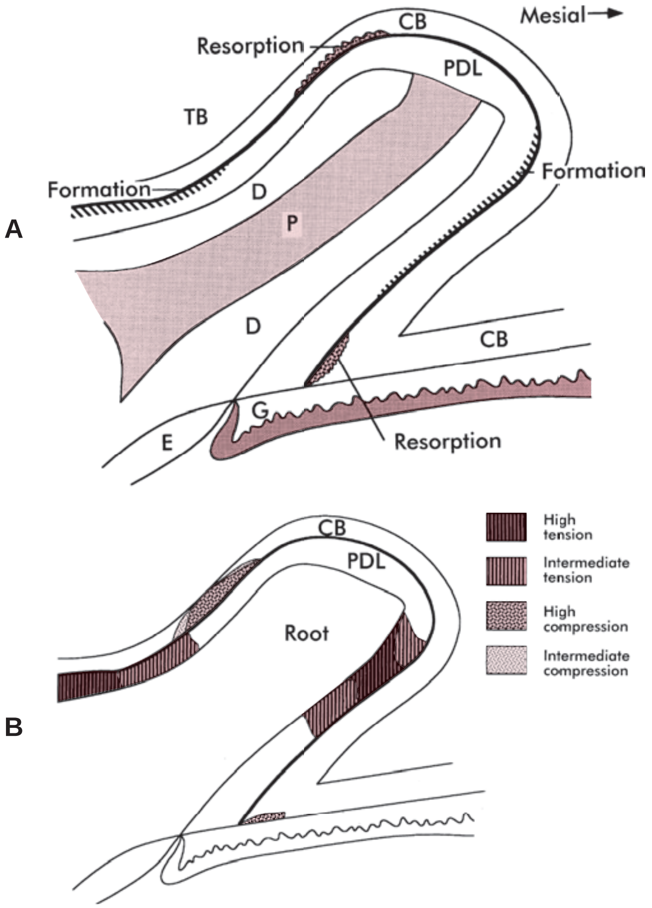


FIGURE 10-62 **A,** The mesial tipping of the rat maxillary first molar results in a typical pattern of bone resorption and formation that produces tooth movement. *G,* Gingiva; *E,* enamel; *D,* dentin; *TB,* trabecular bone; *CB,* cortical bone; *P,* pulp; *PDL,* periodontal ligament. **B,** Finite element model stress analysis of orthodontic tipping indicates that areas of elevated maximal principal stress (tension) in the periodontal ligament and minimal principal stress (compression) in the cortical bone of the lamina dura are associated with areas of bone formation and resorption, respectively. *(From Roberts WE, Garotto LP, Katona TR: Principle of orthodontic biomechanics: metabolic and mechanical control mechanisms. In Carlson DS, Goldstein SA, editors:* Bone biodynamics in orthodontic and orthopedic treatment, *Ann Arbor, 1992, University of Michigan Press.)*

be local mediators of the site-specific resorption that is essential to the tooth movement response.[116]

Osteoclasts are relatively inert cells because they have few specific biochemical receptors. Calcitonin is the only receptor directly related to calcium homeostasis or bone adaptation.

Because osteoblasts and their precursors have a more complete complement of bone-related receptors (i.e., PTH, growth hormone, and estrogen), they may play a role in controlling osteoclasts.[17,143] The intricate bone modeling and remodeling responses that characterize orthodontic tooth movement require close coordination of osteoblastic and osteoclastic function.

Intermittent versus Continuous Mechanics

The rate of tooth movement is determined by initiating and sustaining a coordinated bone resorptive response.[115] The kinetics of continuous mechanics are well known; however, the response to intermittent loads, such as headgear and removable appliances, is less clear. In general, tooth movement is related directly to the number of hours each day that force is applied. However, even when motivation and cooperation are optimal, the effectiveness of similar therapy between patients is inconsistent. This is a physiologic indication that additional variables are involved.

Reitan[111] reports that a short-duration force (12 to 14 hours per day for 15 to 27 days) delivered by a functional appliance triggers a resorptive reaction that lasts a week or more. Apparently this experience with functional appliances does not apply to cyclic intermittent mechanics such the wearing of nighttime headgear. Otherwise, headgear worn at night would be as effective as 24-hour wear. In the absence of specific experiments, interpolation from continuous-force studies appears to be the best explanation available. A 3-hour period of continuous loading is necessary to achieve maximal displacement of a tooth root in the periodontium (see Figure 10-58). If one assumes that at least 3 hours are needed for PDL activation or recovery,[17] continuous wearing of the headgear for 12 hours per day is expected to be more effective than a longer period of wearing the headgear with frequent release of force. The recommendation is that the patient not remove the headgear at all during the daily interval of wear. Removing the device for meals or sports compromises the biomechanical activation of the periodontium. The complex biological response associated with irregular force application probably is the main factor in the unpredictable response to headgear or removable appliances.

Another possible variable in the response to intermittent force is the circadian rhythm of PDL proliferation and differentiation (see Figures 10-69 and 10-70). Maximal cell proliferation in the PDL occurs during the resting hours[149,150]—daytime for rats, nighttime for human beings. Differentiation to preosteoblasts, the key rate-limiting step in osteoblast differentiation, occurs during the late resting and early arousal periods.[144] These data suggest that wearing headgear or a removable appliance at night is more effective than wearing the same appliance for an equal period during the day.[150]

Differential Anchorage

The density of the alveolar bone and the cross-sectional area of the roots in the plane perpendicular to the direction of tooth movement are the primary considerations for assessing anchorage potential. The volume of osseous tissue that must be resorbed for a tooth to move a given distance is its anchorage value. If all bone offered the

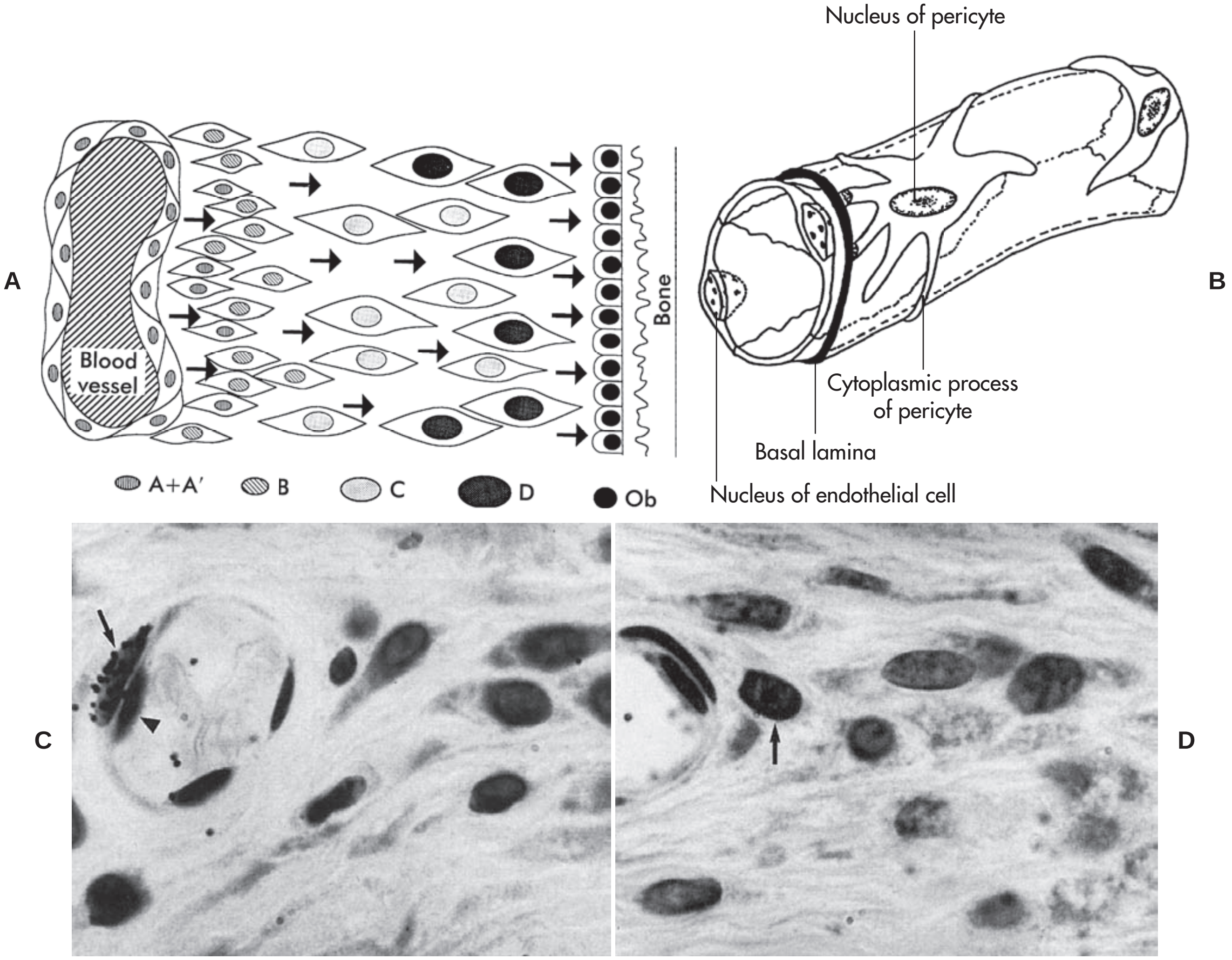
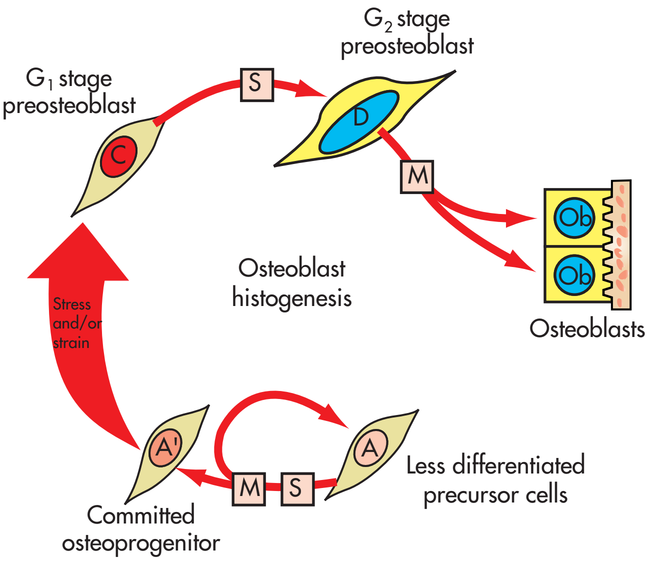


FIGURE 10-63 **A,** Less differentiated precursor cells (A cells) are a paravascular population. They differentiate to committed osteoprogenitor cells (A′ cells), which migrate away from the blood vessel. Traversing the low-cell density zone, the A′ cells differentiate to G_1-stage preosteoblasts (C cells), which synthesize DNA and become G_2-stage preosteoblasts (D cells). **B,** A pericyte, a distinct polymorphic cell of mesenchymal origin, partly encircles a microvessel and shares a common basal lamina with an endothelial cell. **C,** Photomicrograph of autoradiography of an expanded interpremaxillary suture, showing labeled pericyte (*arrow*) and unlabeled endothelial cell (*arrowhead*). (Stained with hematoxylin and eosin; original magnification ×1000 under oil immersion.] **D,** Photomicrograph of autoradiography of an expanded interpremaxillary suture, showing an activated pericyte (*arrow*) that has partly separated from the basal lamina of the blood vessel. The nuclear pattern of the activated pericyte shows that it is in the prophase of mitosis. (Stained with hematoxylin and eosin; original magnification ×1000 under oil immersion.) *(From Chang H-N, et al: Angiogenesis and osteogenesis in an orthopedically expanded suture,* Am J Orthod Dentofac Orthop *111:382, 1997.)*

same resistance to tooth movement, the anchorage potential of maxillary and mandibular molars would be about the same. However, clinical experience shows that maxillary molars usually have less anchorage value than mandibular molars in the same patient. A common example is space closure in a Class I four premolar extraction case; it often is necessary to use headgear on the maxillary first molars to maintain the Class I relationship. The relative resistance of mandibular molars to mesial movement is a well-known principle of differential mechanics.

Why are mandibular molars usually more difficult to move mesially than maxillary molars? At least two physiologic factors can be considered: (1) the thin cortices and trabecular bone of the maxilla (see Figures 10-2, 10-3, and 10-5) offer less resistance to resorption than the thick cortices and more coarse trabeculae of the mandible (see Figures 10-4 and 10-5), and (2) the leading root of mandibular molars being translated mesially forms bone that is far more dense than the bone formed by translating maxillary molars mesially (Figure 10-73).[136] The reason mandibular molars form more



G_2 stage preosteoblast
G_1 stage preosteoblast
S
C
D
M
Ob
Ob
Osteoblasts
Osteoblast histogenesis
Stress and/or strain
A'
M
S
A
Less differentiated precursor cells
Committed osteoprogenitor

FIGURE 10-64 Frequency distribution of nuclear volume for fibroblast-like cells in unstimulated rat periodontal ligament. *A,* A′, C, and D cells are a morphologic classification based on peaks in the distribution curve. The osteoblast histogenesis sequence is a progression of five morphologically and kinetically distinguishable cells. The process involves two DNA S phases and two mitotic (M) events. *(Redrawn from Roberts WE, Morey ER: Proliferation and differentiation sequence of osteoblast histogenesis under physiological conditions in rat periodontal ligament,* Am J Anat *174:105, 1985.)*

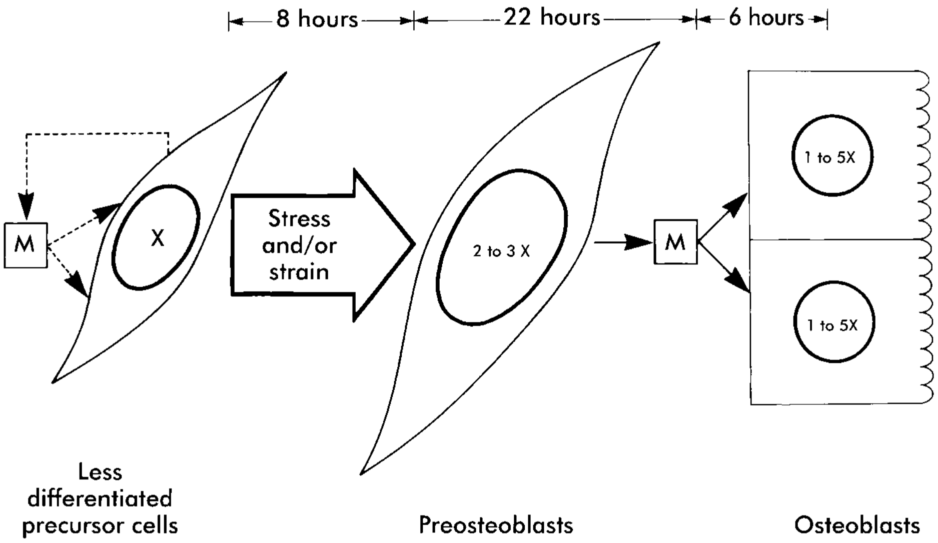


FIGURE 10-65 Differentiation of less differentiated precursor cells to preosteoblasts involves an increase in nuclear volume mediated by stress, strain, or both. The increase in nuclear size is a morphologic manifestation of change in genomic expression (differentiation). *(From Roberts WE, Mozsary PG, Klingler E: Nuclear size as a cell kinetic marker for osteoblast differentiation,* Am J Anat *165:373, 1982.)*

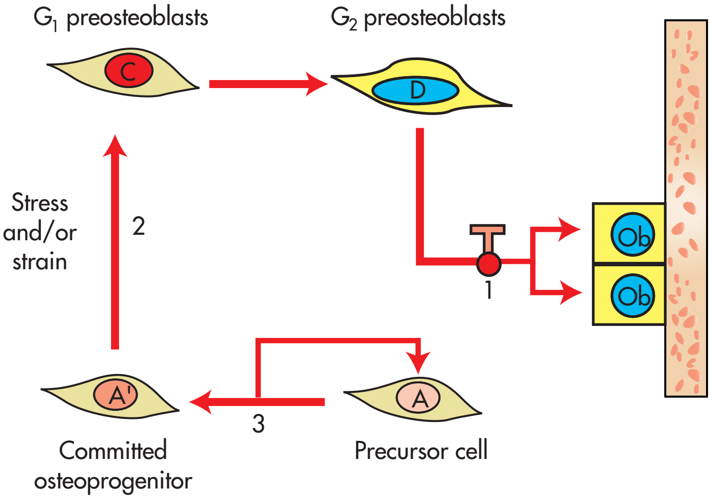


FIGURE 10-66 The control scheme for osteogenic induction of a relatively quiescent periodontal ligament cell population involves (*1*) release of the G_2 block, allowing mitosis to form two osteoblasts (Ob); (*2*) mechanically mediated differentiation to preosteoblasts (A′ → C); and (*3*) increased proliferation of precursor cells to produce more committed osteoprogenitor cells (A′). *(Redrawn from Roberts WE, Garotto LP, Katona TR: Principle of orthodontic biomechanics: metabolic and mechanical control mechanisms. In Carlson DS, Goldstein SA, editors:* Bone biodynamics in orthodontic and orthopedic treatment, *Ann Arbor, 1992, University of Michigan Press.)*

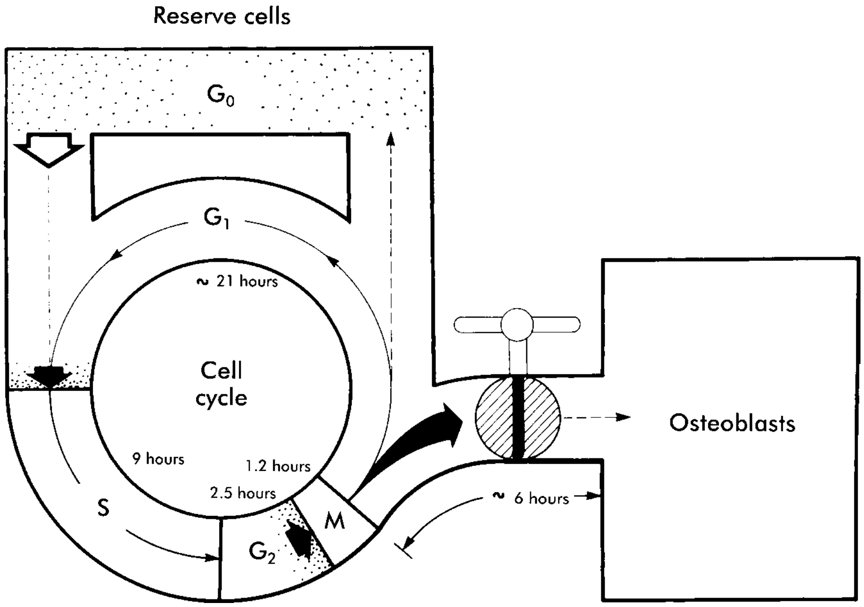


FIGURE 10-67 Composite cell cycle diagram shows the approximate duration and various phases of the cell cycle. The cells arrested at the end of the G_1 and G_2 phases are referred to as G_1- or G_2-blocked cells. These cells can be released by metabolic or mechanical stimuli or both (see Figure 10-66). *(From Roberts WE, Goodwin WC, Heiner SR: Cellular response to orthodontic force,* Dent Clin North Am *25:3, 1981.)*

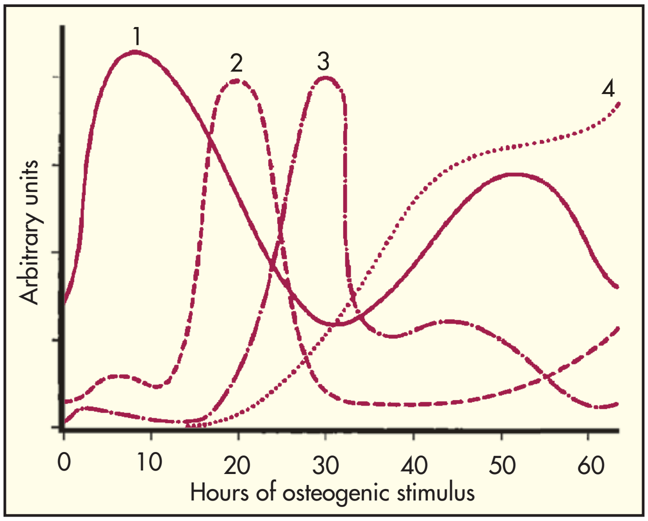


FIGURE 10-68 Cell kinetic events that produce new osteoblasts after orthodontic stimulus are represented by peaks in the curves from *left* to *right:* (*1*) accumulation of preosteoblasts (A′ → C); (*2*) DNA synthesis to form D cells; (*3*) mitosis of D cells; and (*4*) accumulation of mature osteoblasts. This sequence established D cells as the immediate proliferating progenitors of osteoblasts. *(From Roberts WE, Mozsary PG, Klingler E:* Am J Anat *165:373, 1982.)*

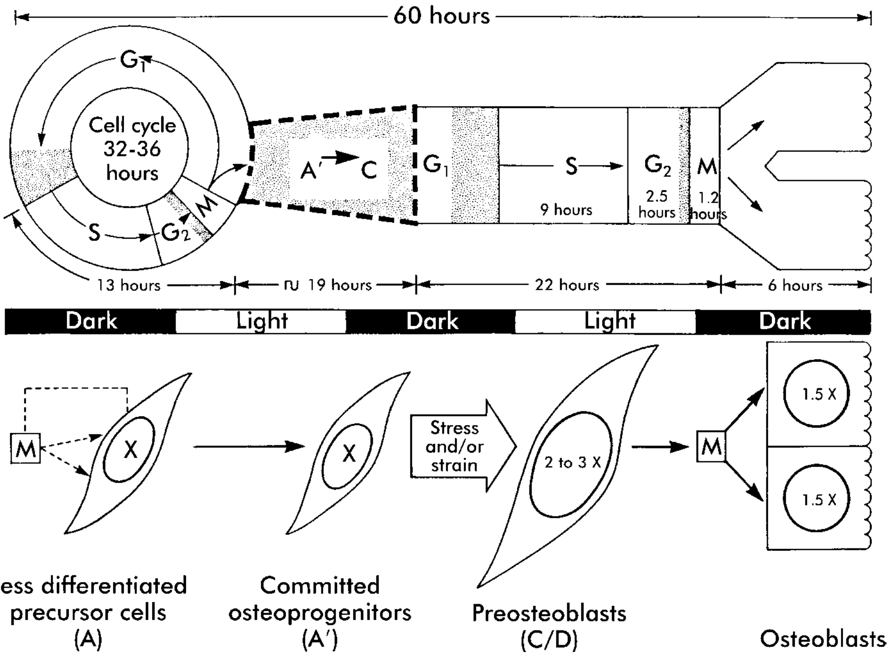


FIGURE 10-69 Photoperiod (circadian rhythm) influence on physiologic osteoblast histogenesis in rat periodontal ligament. Note that the A′ → C increase in nuclear size occurs during the late resting and early arousal phases. The overall osteoblast differentiation sequence is 60 hours, five alternating dark/light cycles of 12 hours each. *(From Roberts WE, Morey ER: Proliferation and differentiation sequence of osteoblast histogenesis under physiological conditions in rat periodontal ligament,* Am J Anat *174:105, 1985.)*

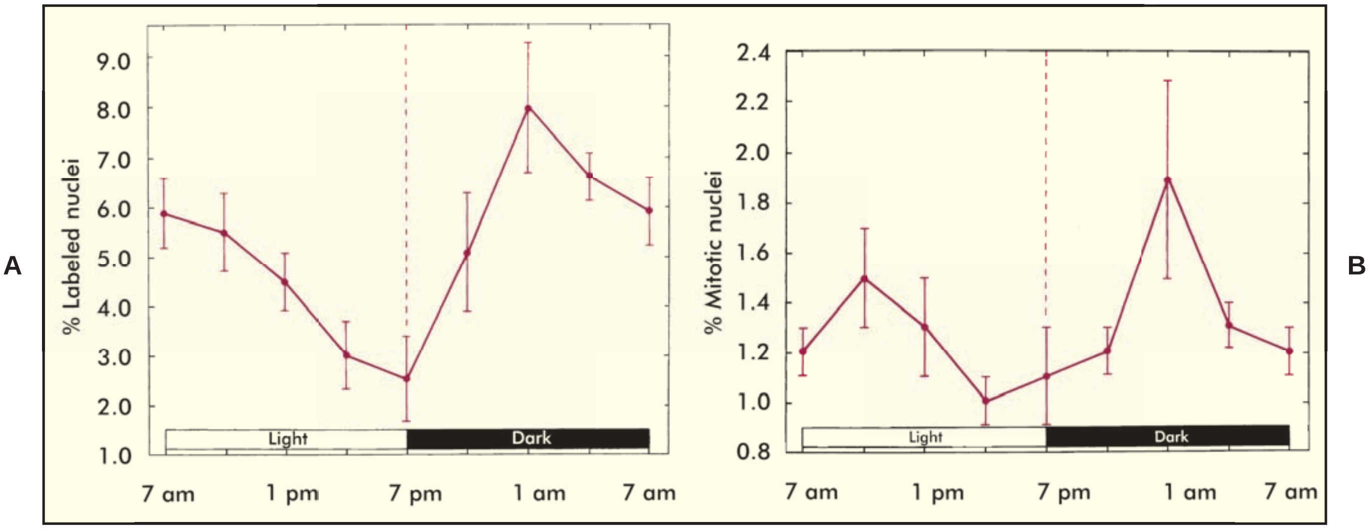


FIGURE 10-70 **A,** Circadian rhythm (photoperiod) of S phase cells in unstimulated rat periodontal ligament along a natural bone-forming surface. **B,** Circadian rhythm (photoperiod) of mitotic cells in unstimulated rat periodontal ligament along a natural bone-forming surface. *(From Roberts WE, Morey ER: Proliferation and differentiation sequence of osteoblast histogenesis under physiological conditions in rat periodontal ligament,* Am J Anat *174:105, 1985.)*

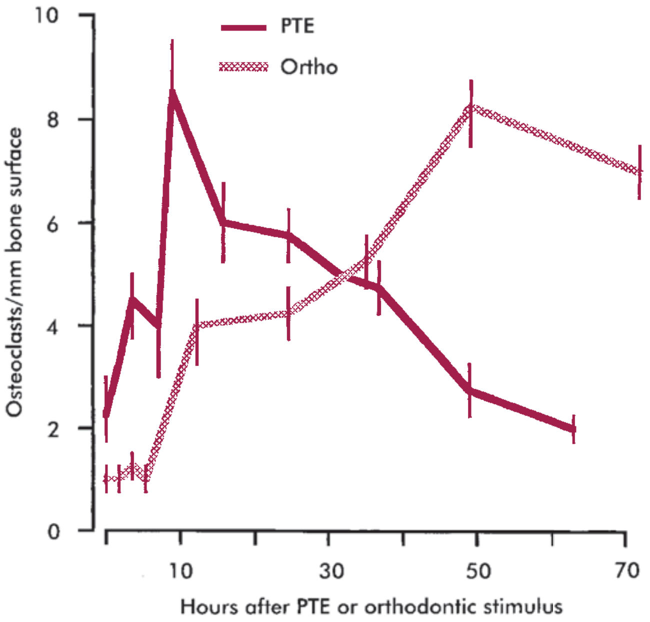


FIGURE 10-71 Metabolic (parathyroid extract [PTE]) versus mechanical (orthodontic) stimulation of periodontal ligament osteoclastic activity. *(From Roberts WE, Ferguson DJ: Cell kinetics of the periodontal ligament. In Norton L, Burstone CB, editors:* The biology of tooth movement, *Boca Raton, FL, 1989, CRC Press.)*

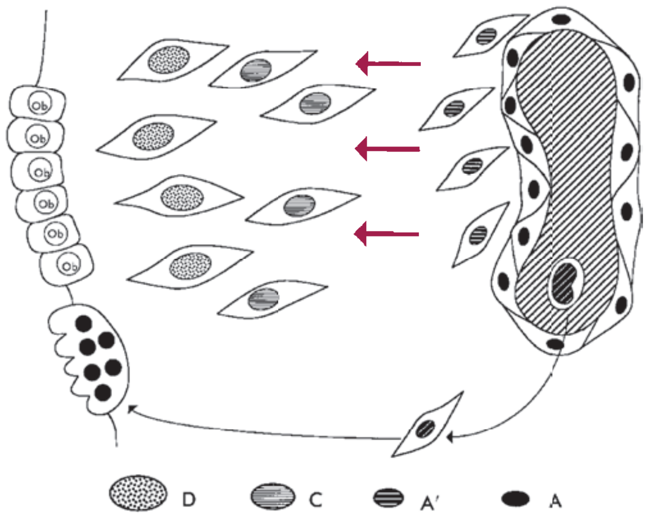


FIGURE 10-72 Circulating osteoclast precursor cells, derived from the marrow, are the origin of the preosteoclasts in the periodontal ligament that form osteoclasts (lower pathway). The paravascular origin of osteoblasts from A, A′, C, and D cells is an independent mechanism. At the local tissue level no common progenitors are found for osteoblasts and osteoclasts.

dense bone than maxillary molars is unclear; however, it may be that new bone formed in the maxilla is remodeled more rapidly. In general, bones composed primarily of trabeculae remodel more rapidly than those composed primarily of cortical bone.[48,151]

Why is the alveolar process that supports the mandibular molars more dense than maxillary molars? Functional loading dictates the osseous anatomy for the opposing jaws: the maxilla is predominantly trabecular bone with thin cortices, similar to a vertebral body or an epiphysis (see Figures 10-2, 10-4, and 10-5); the mandible has thick cortices, similar to the diaphysis of a major long bone (see Figures 10-4 and 10-5). Although the forces of occlusion are distributed equally to the maxilla and mandible, the maxilla transfers a major fraction of functional loads to the rest of the cranium.

The loads (compression, tension, and torsion) to which the maxilla and the mandible are exposed are

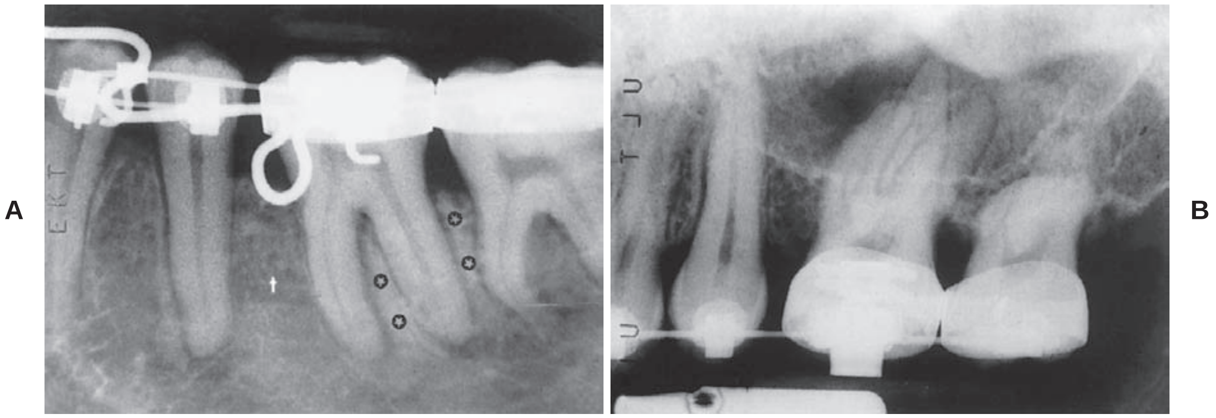


FIGURE 10-73 **A,** Progressive mesial translation of second and third mandibular molars generates dense cortical bone (*stars*) that is more resistant to resorption than the trabecular bone (*t*) ahead of the first molar. **B,** Mesial movement of the second and third molars in the maxilla of the same patient fails to demonstrate dense cortical bone distal to the moving roots. *(From Roberts WE, Garotto LP, Katona TR: Principle of orthodontic biomechanics: metabolic and mechanical control mechanisms. In Carlson DS, Goldstein SA, editors:* Bone biodynamics in orthodontic and orthopedic treatment, *Ann Arbor, 1992, University of Michigan Press.)*

different. The mandible is subjected to substantial torsion and flexure caused by muscle pull and masticatory function.[5,152] Thick mandibular cortices are needed to resist the torsional and bending strain (see Figures 10-5 and 10-6). The maxilla, however, is loaded predominantly in compression, has no major muscle attachments, and transfers much of its load to the rest of the cranium. Because of its entirely different functional role, the maxilla is predominantly trabecular bone with thin cortices (see Figures 10-2 to 10-4). This anatomic configuration is similar to that of other bones loaded primarily in compression (e.g., proximal tibia and vertebral bodies of the spine).

Rate of Tooth Movement

A histomorphometric evaluation of alveolar bone turnover between the maxilla and the mandible during experimental tooth movement in dogs has defined the differential response of the jaws to tooth movement.[151] A similar mini-screw anchored force system of 200 to 250 *g* was applied to premolars in the maxillary and mandibular arches for 4 or 12 weeks. The tooth movement response was monitored with radiographs and fluorescent bone labels. Significantly more orthodontic tooth movement was observed for maxillary than for mandibular teeth. The primary histomorphometric analysis indicated that, after 4 weeks of tooth movement, a marginal increase in resorptive parameters was associated with a decrease of bone volume at both the tension and compression sites. On the other hand, after 12 weeks of tooth movement, secondary histomorphometric analysis indicated an increase in the bone formation rate, resulting in increased woven bone formation, especially at the tension sites. These results indicate that tooth movement is a regional acceleratory phenomenon (RAP), manifested as increased bone turnover in the alveolar process as the teeth move through it. The RAP of resisting bone can be enhanced by corticotomies.[154]

From a clinical perspective, maxillary bone is more responsive to orthodontics because it is primarily composed of trabecular bone.[153] The rate of tooth movement is the inverse of anchorage potential; the same physiologic principles apply. Clinical studies using endosseous implants for anchorage[100] have provided excellent opportunities to assess the rate of tooth movement through dense cortical bone in the posterior mandible (see Figure 10-73, *A*) compared with the less dense trabecular bone of the posterior maxilla (see Figure 10-73, *B*). The enhanced anchorage value of mandibular molars is related to the high-density bone formed as the leading roots are moved mesially. After a few months of mesial translation, the trailing roots engage the high-density bone formed by the leading root and the rate of tooth movement declines (Figure 10-74).

Overall, the maximal rate of translation of the midroot area through dense cortical bone is about 0.5 mm per month for the first few months; the rate then declines to less than 0.3 mm per month until the first molar extraction site is closed (see Figure 10-74). A composite analysis of four similar cases of molar translation in adults showed that teeth moved out at a rate of about 0.6 mm per month for about 8 months; the rate decreased to 0.33 mm per month as the trailing (distal) root engaged the dense bone formed by the leading (mesial) root (Figure 10-75).

When teeth are moved continuously in the same direction, the remodeling rate increases in compact bone immediately ahead of the moving tooth (see Figures 10-54 and 10-55). This enhanced remodeling process probably is related to the regional acceleratory phenomenon commonly noted in osseous wound healing.

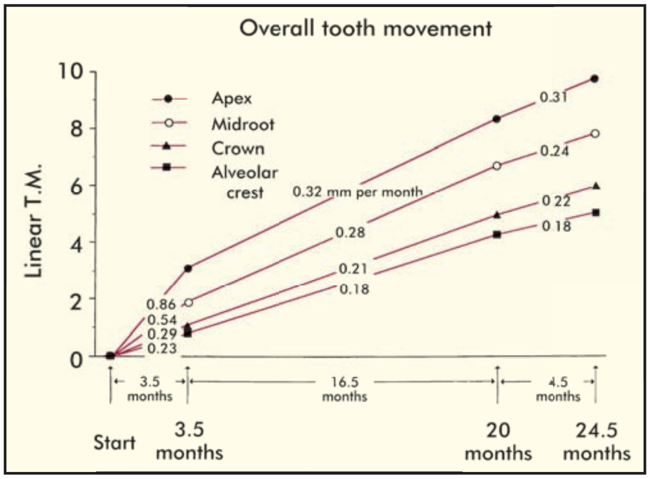


FIGURE 10-74 Overall tooth movement curve for lower second and third molars demonstrates mesial root movement and translation of 8 to 10 mm in about 2 years. Note that the rapid movement of the first 3.5 months (as much as 0.86 mm a month) slows to about 0.3 mm a month for the duration of space closure.

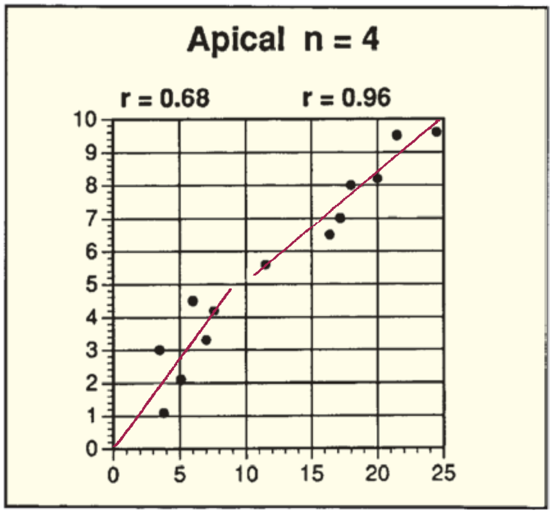


FIGURE 10-75 Separate linear regressions plotted for tooth movement during the first 8 months compared with regression seen after about 12 months in four patients in whom mesial root movement was initiated at the start of treatment. *[From Roberts WE, Arbuckle GR, Analoui M: Rate of mesial translation of mandibular molars using implant-anchored mechanics,* Angle Orthod *66(5):335, 1996.]*

Cutting/filling cones are the means of osteoclast access to the inner portion of dense compacta (see Figure 10-22). This remodeling mechanism appears to be particularly important for resorbing the dense cortical bone formed by the leading root during mesial movement of lower molars (see Figure 10-73). Note the radiolucent areas in the dense compact bone.

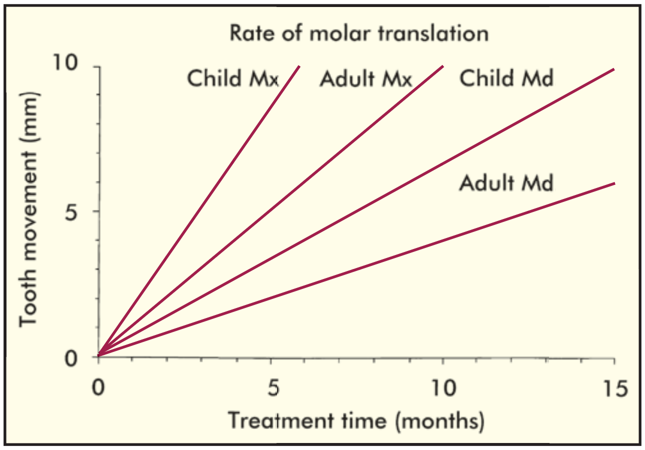


FIGURE 10-76 Relative rates of molar translation in both jaws of rapidly growing children compared with the rates in adults.

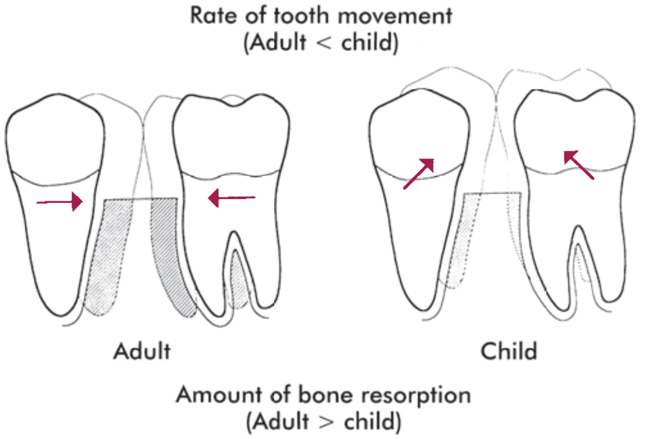


FIGURE 10-77 The rate of molar translation is related directly to the amount and density of bone that must be resorbed. Because extrusion is associated with growth, relatively less bone must be resorbed in translation of children's molars.

Figure 10-76 is a summary of the relative rates of molar translation in the upper and lower jaws of growing children and adults. A maximal rate approaching 2 mm per month is possible with space closure mechanics or 24-hour-per-day headgear wear by a rapidly growing child (Child Mx). Similar mechanics in a nongrowing adult can translate upper molars about 1 mm per month (Adult Mx). Mesial translation of lower molars in a child occurs at a rate of about 0.7 mm per month (Child Md). The slowest molar translation (0.3 mm per month) is in the lower arch of adults (Adult Md). Overall, the same teeth in growing children move about twice as fast as they move in adults. Certainly histologic factors, such as less dense alveolar bone and more cellular PDL,[26] are relevant factors; however, growth-related extrusion is the principal reason that space closure is almost twice as rapid in children. Figure 10-77 shows the considerably smaller volume of bone that is resorbed during space closure in a child compared with that in an adult. In general, the rate of tooth movement is inversely related to bone density and the volume of bone resorbed.

Rates for orthodontic tipping movements usually are higher but are more variable than for translation. No well-controlled studies of tipping in various intraoral sites of children and adults are available; however, some interesting theoretical considerations have been offered. When teeth are moved rapidly, immature new bone can form at a rate of 100 mm/day or more (more than 3 mm per month). This rate of tooth movement probably is never achieved during routine treatment. However, premolar and canine tipping of about 2 mm per month may be achieved with removable appliances in the maxillary arch of growing children.

In brief, three principal variables determine the rate of tooth movement: (1) growth, (2) bone density, and (3) type of tooth movement. Alveolar bone of the maxilla is less dense than that of the mandible because it has a higher ratio of cancellous bone to cortical bone. Bone in children generally is less dense (more porous or cancellous) than bone in adults. Cancellous or trabecular bone has more surface area available for resorption, which is important because bone that impedes tooth movement can be resorbed from all sides. Cortical bone is restricted largely to frontal and undermining resorption mechanisms in the PDL. In general, children have a higher rate of bone remodeling than adults. In simple terms, more osteoclasts are present in the bone that can help with the task of removing the osseous tissue impeding tooth movement.

The teeth of growing children extrude as they move through bone. One must remember that for the basilar bone of the jaws to separate 1 to 2 cm during 2 years of orthodontic treatment is not uncommon. This means that the teeth of children move as much by differential apposition (guided eruption) as by resorption (see Figure 10-77). Tipping the teeth requires less resorption of bone adjacent to the middle of the root. This bone, which is farthest from bone surfaces, probably is the most difficult for the osteoclasts to access. Eliminating the most difficult part of the resorptive process probably is the reason teeth move faster by tipping than by translation. Considering all the variables of age, arch, and type of tooth movement, maxillary buccal segments in children move as much as 4 times faster than posterior mandibular segments in adults (see Figure 10-76).

To date almost all studies of the rate of tooth movement have used two-dimensional methods of analysis. However, tooth movement is actually a three-dimensional phenomenon and more advanced methods of analyis are needed. Viecilli et al.[72] demonstated that the movement of mouse molars is not along the line of force, which may reflect the asymmetric distribution of the tooth's root structure relative to supporting bone. More studies of the rate of tooth movement are needed at the three-dimensional level.[155]

Periodontitis and Orthodontics

Osteoclasts are hardy cells that thrive in a pathologic environment. Osteoblasts, however, are vascularly dependent cells, and their histogenesis is disrupted easily.[17,144] Therefore, most skeletal deficits probably are errors in bone formation rather than resorption. A good example of the fragility of bone formation is suppression of osteoblast differentiation by inflammatory disease processes.[91]

Orthodontics often is a useful adjunct for enhancing periodontal health, although moving teeth when progressive periodontal disease is present invites disaster.[91] Tooth movement in the alveolar process stimulates resorption and formation. Osteoclasts thrive in an inflammatory environment because they originate in the marrow, a protective site removed from the localized lesion. Preosteoclasts are attracted to the inflammatory site by cytokine mediators.[116] Vascularly mediated osteoblast histogenesis, however, is suppressed strongly by inflammatory disease. Therefore, when teeth are moved in the presence of active periodontal disease, resorption is normal or even enhanced and bone formation is inhibited. In a patient who has periodontitis, orthodontics may exacerbate the disease process, resulting in a rapid loss of supporting bone (Figure 10-78).

Endosseous Implants

A major problem in orthodontics and facial orthopedics is anchorage control.[27] Undesirable movement of the anchorage units is a common problem that limits the

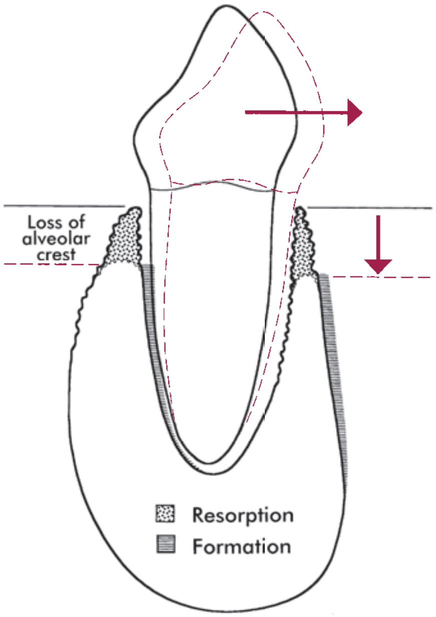


FIGURE 10-78 Because active periodontitis enhances resorption and inhibits apposition, orthodontics in patients with this condition often results in a severe loss of alveolar bone support.

therapeutic range of biomechanics.[156] An important application of the basic principles of bone physiology is the use of rigid endosseous implants for orthodontic and orthopedic anchorage. Animal studies[40] and clinical trials of custom orthodontic devices[34] have established that rigidly integrated implants do not move in response to conventional orthodontic and orthopedic forces. These devices are opening new horizons in the management of asymmetry, mutilated dentition, severe malocclusion, and craniofacial deformity.[157]

A preclinical study in dogs tested the anchorage potential of two prosthetic-type titanium implants: (1) a prototype of an endosseous device with a cervical post, asymmetric threads, and an acid-etched surface and (2) a commercially available implant with symmetric threads (Figure 10-79). Based on label incidence (Figure 10-80, *A*) and the relative number of new osteons in microradiographs (Figure 10-80, *B*), the rate of bone remodeling near the implant was higher compared with the basilar mandible only a few millimeters away.[158] Compared with titanium implants with a smooth surface, the degree of remodeling at the interface is greater for threaded implants placed in a tapped bone preparation.[27] This may be related to the increased resistance of threaded implants to torsional loads over time.[159]

Direct bone apposition at the endosseous interface results in rigid fixation (osseointegration).[160] From an anchorage perspective, a rigid endosseous implant is the functional equivalent of an ankylosed tooth. Complete bony encapsulation is not necessary for an implant to serve as a rigid anchorage unit. The crucial feature is indefinite maintenance of rigidity despite continuous orthodontic loads. Over time, orthodontically loaded implants achieve a greater fraction of direct osseous interface.[149,159] From an orthodontic and orthopedic perspective, titanium implants can resist substantial continuous loads (1 to 3 N superimposed on function) indefinitely. Histologic analysis with multiple fluorochrome labels and microradiography confirm that rigidly integrated implants do not move relative to adjacent bone (see Figure 10-80).[40] By definition, maintaining a fixed relationship with supporting bone is true osseous anchorage. Endosseous (osseointegrated) implants are well suited to many demanding orthodontic applications.[34,55]

Routine use of rigid implants for prosthetic or orthodontic applications requires that fixtures be placed between or near the roots of teeth. Inadvertent impingement on the PDL and the root of an adjacent tooth still may provide an acceptable result (Figure 10-81). Cementum repair occurs where the root is cut, the PDL reorganizes, and the implant surface is integrated rigidly with osseous tissue. No evidence exists of ankylosis of the tooth.[40]

Retromolar Implant Anchorage. The isolated loss of a lower first molar with a retained third molar is a common problem. Rather than extract the third molar and replace the first molar with a three-unit bridge, mesial translation of second and third molars to close the edentulous spaces often is preferable (Figure 10-82). The first case with long-term follow-up has been published.[34] Because of the increasing incidence of progressive bone loss and fatigue fracture associated with single tooth implants in lower first and second molar areas, the orthodontic option for mesially translating the molars to close the space is increasing in popularity.

External Abutment Mechanism. An anchorage wire that is secured to a retromolar implant can be used to intrude and protract mandibular second and third molars to close an atrophic first molar extraction site (see Figure 10-82, *B*).[20] The tipping and extrusion of residual lower molars limit potential orthodontic repositioning. Rigid

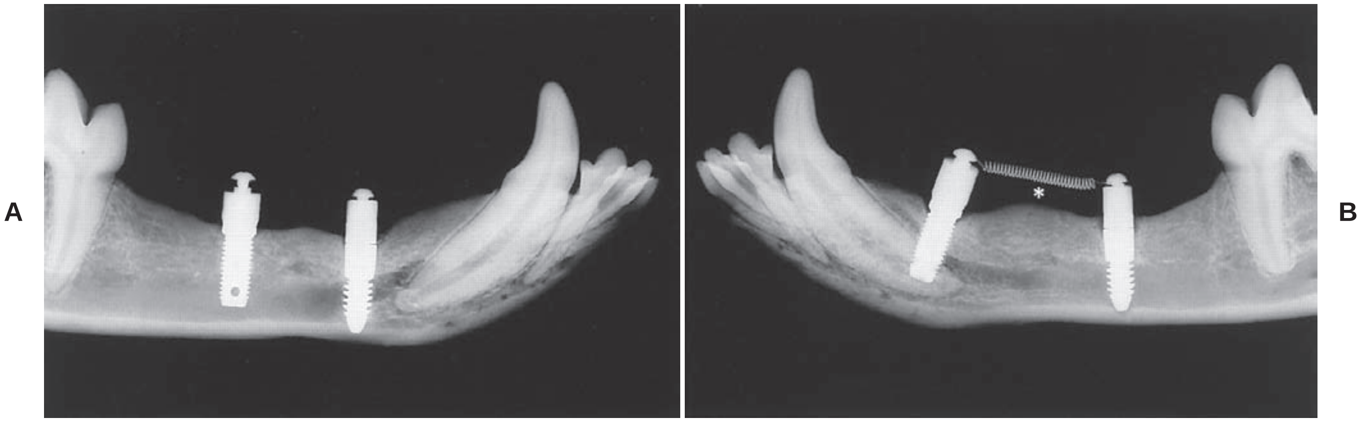


FIGURE 10-79 **A,** Two titanium implants of different design were placed in the partly edentulous mandible of young adult dogs. **B,** After 2 months of unloaded healing, a 3-N compressive load was applied between the implants for 4 months. Increased periosteal apposition (*) was noted between the implants of some dogs. None of the rigidly integrated fixtures was loosened by the continuous load superimposed on function. *(From Roberts WE, et al: Rigid endosseous implants for orthodontic and orthopedic anchorage,* Angle Orthod *59:247, 1989.)*

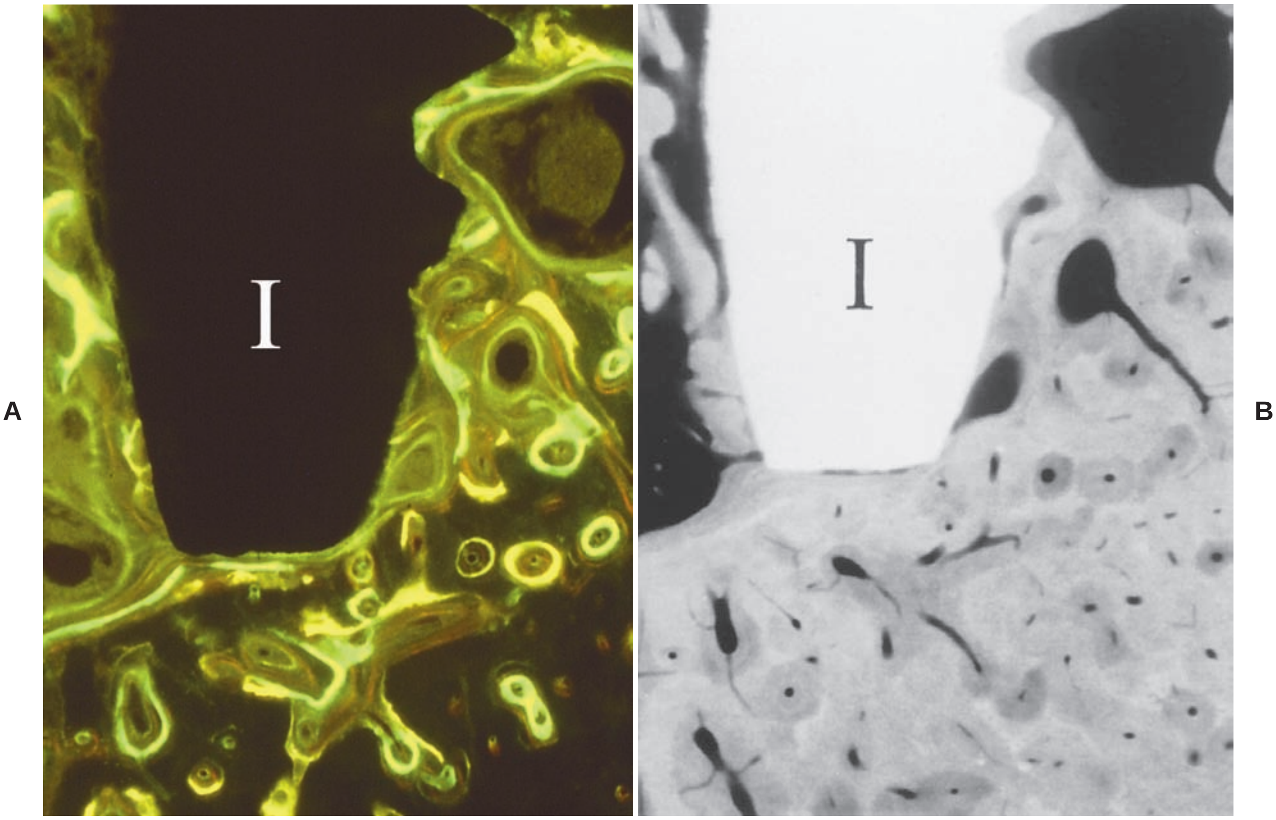


FIGURE 10-80 **A,** Multiple fluorochrome labels in bone adjacent to an implant (*I*) show a high rate of remodeling at the bone-implant surface. **B,** Microradiographic image of the same section shows direct bone contact on the surface of the implant. *(From Roberts WE, Garotto LP, Katona TR: Principle of orthodontic biomechanics: metabolic and mechanical control mechanisms. In Carlson DS, Goldstein SA, editors:* Bone biodynamics in orthodontic and orthopedic treatment, *Ann Arbor, 1992, University of Michigan Press.)*

retromolar implants offer a unique capability for intrusion and alignment. Figure 10-83 demonstrates the mechanics for achieving three-dimensional control to intrude the third molar to the plane of occlusion and translate both teeth mesially. Cephalometric tracings (Figure 10-84) document the more than 10 mm of mesial translation and its stability. Panoramic radiographs show the initial alignment (Figure 10-85, *A*) and the final space closure (Figure 10-85, *B*). Clinical details have been published.[34]

Histologic analysis of implants recovered after completion of treatment has revealed important information about the continuous remodeling process that maintains the rigid integration and anchorage value of the endosseous device. Two intravital bone labels, administered within 2 weeks of implant recovery, have shown a continuing high rate of bone remodeling (more than 500% per year) within 1 mm of the implant surface (Figure 10-85, *C, D*). This biological mechanism apparently is the means by which rigid osseous integration is maintained indefinitely.[30,34] If no fracture is present at the implant interface or in its supporting bone, rigid implants are not moved by orthodontic loads.[10,34,40,138] Well-integrated endosseous implants remain rigid despite

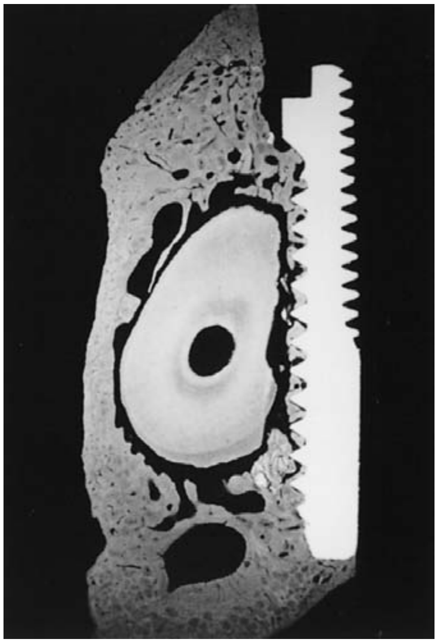


FIGURE 10-81 An endosseous implant inadvertently impinged on the root of a canine. The implant successfully integrated with bone and served as a rigid anchor for orthopedic loading. *(From Roberts WE, et al: Rigid endosseous implants for orthodontic and orthopedic anchorage,* Angle Orthod *59:247, 1989.)*

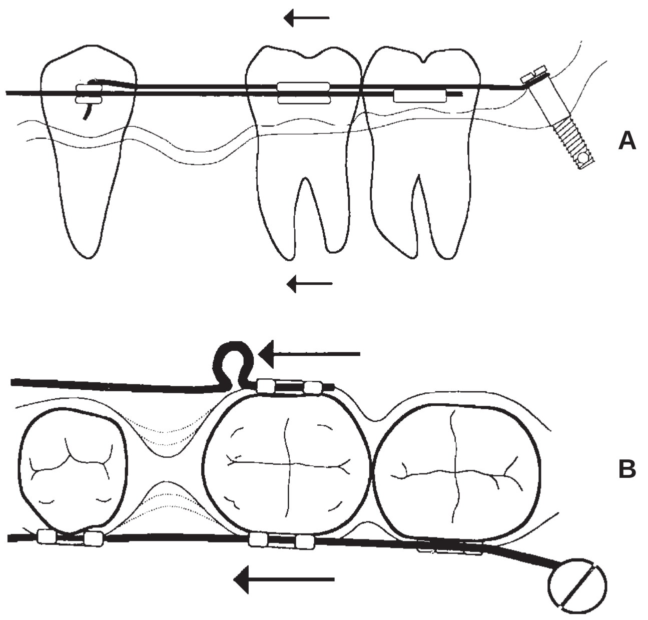


FIGURE 10-82 **A,** The mechanics of using a retromolar implant with an external abutment as anchorage to stabilize the premolar anterior to an extraction site. **B,** Using buccal and lingual mechanics to balance the load and shield the periosteum in the extraction site, the atrophic extraction site is closed without periodontal compromise of any of the adjacent teeth. *(From Roberts WE, Garotto LP, Katona TR: Principle of orthodontic biomechanics: metabolic and mechanical control mechanisms. In Carlson DS, Goldstein SA, editors:* Bone biodynamics in orthodontic and orthopedic treatment, *Ann Arbor, 1992, University of Michigan Press.)*

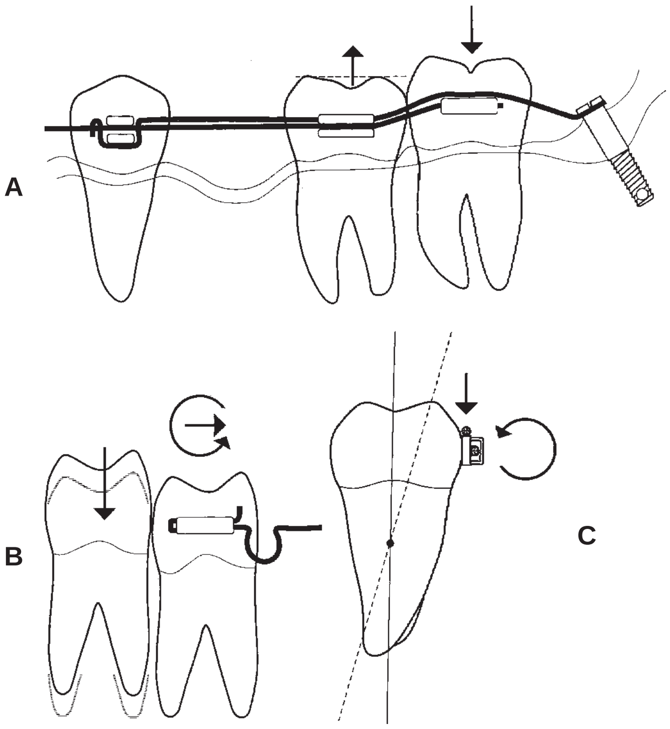


FIGURE 10-83 **A,** The mechanics of intruding a third molar with implant anchorage before space closure. **B,** A removable lingual arch prevents extrusion of the second molar. C, Because the intrusive force on the third molar is buccal to the center of resistance, the tooth tends to tip buccally. This problem is controlled by placing lingual crown torque in the rectangular wire inserted in the tube. *(From Roberts WE, Garotto LP, Katona TR: Principle of orthodontic biomechanics: metabolic and mechanical control mechanisms. In Carlson DS, Goldstein SA, editors:* Bone biodynamics in orthodontic and orthopedic treatment, *Ann Arbor, 1992, University of Michigan Press.)*

continued remodeling of the bone supporting them because only a portion of the osseous resorbed interface is turned over at any given time.[34] Figure 10-86 shows the mechanics for mesial translation of molars to close an edentulous space when a premolar is congenitally missing. Rigid endosseous implants show great promise for considerably extending the therapeutic possibilities of orthodontics and dentofacial orthopedics.

Internal Abutment Mechanism. The 0.019- × 0.025-inch titanium-molybdenum alloy anchorage wire (Ormco Corp., Orange, CA) is secured to the endosseous implant when the implant is placed (Figure 10-87). A 7- to 10 × 3.75-mm Brånemark implant (Nobel Biocare, Gothenburg, Sweden) is placed in the retromolar area 3 to 5 mm buccal and distal to the terminal molar. The end of the anchorage wire is bent into a circle and firmly attached to the implant with a standard healing cap (Figures 10-88 and 10-89). This "internal abutment" approach offers a number of advantages over the original external abutment method:

- Minimal surgery: No postoperative uncovering is required.
- Less expense: Only one surgical procedure is needed, and no transmucosal abutment is required.
- Better hygiene: Wire exiting in the depth of the buccal fold requires little or no periodontal maintenance.
- Immediate loading: No healing period is necessary.
- More versatile intrusive force: Control of the intrusive load on the mandibular molars is easier.

Fifteen years of experience with the internal abutment mechanism (Figure 10-90) has established its utility as an implant anchorage mechanism for managing edentulous spaces in the mandibular buccal segments.[136,161–163]

Indirect anchorage with a retromolar implant is proving to be useful for closing missing second premolar and molar spaces in growing children.[164] However, an increased tendency for soft tissue irritation exists if the anchorage wire is positioned in the depth of the mucobuccal fold (Figure 10-91, *A*). When the wire is repositioned to just under the brackets of the molars (Figure 10-91, *B*), soft tissue irritation ceased to be a problem and the second molar space was closed in about 10 months.

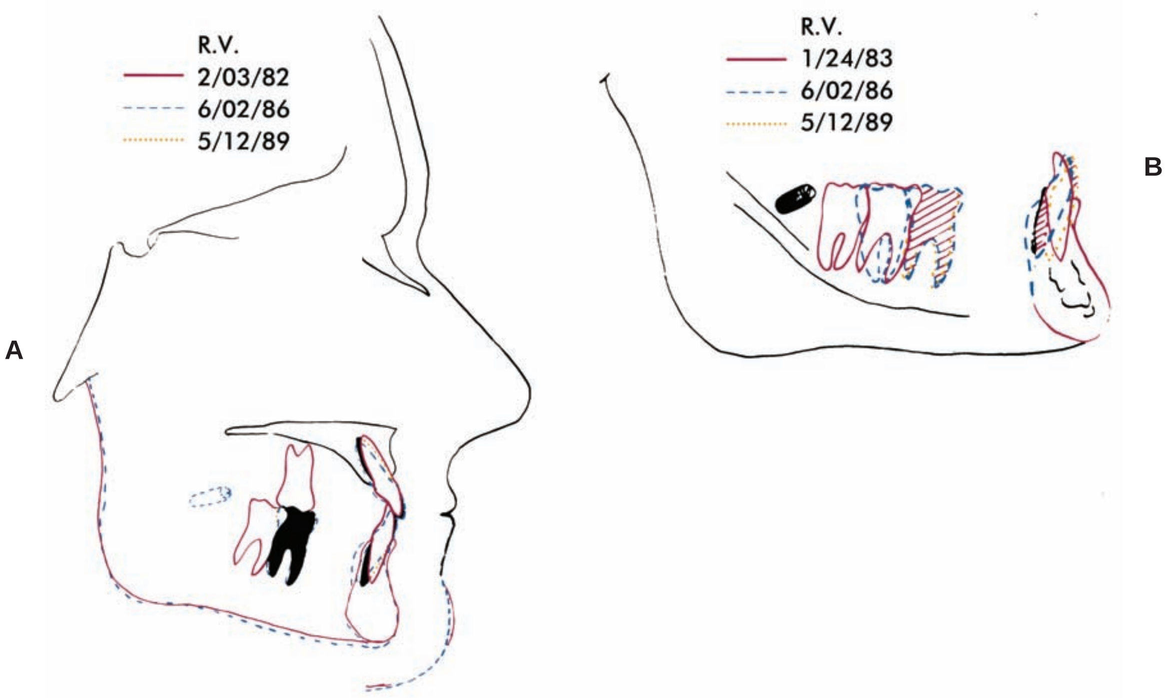


FIGURE 10-84 **A,** Pretreatment, finish, and 3-year postretention cephalometric tracings document 10 to 12 mm of molar translation to close an atrophic first molar extraction site. **B,** Mandibular superimposition shows the mesial movement of the second and third molars, as well as lingual root torque of the lower incisors. *(From Roberts WE, Marshall KJ, Mozsary PG: Rigid endosseous implant utilized as anchorage to protract molars and close on atrophic extraction site,* Angle Orthod *60:135, 1990.)*

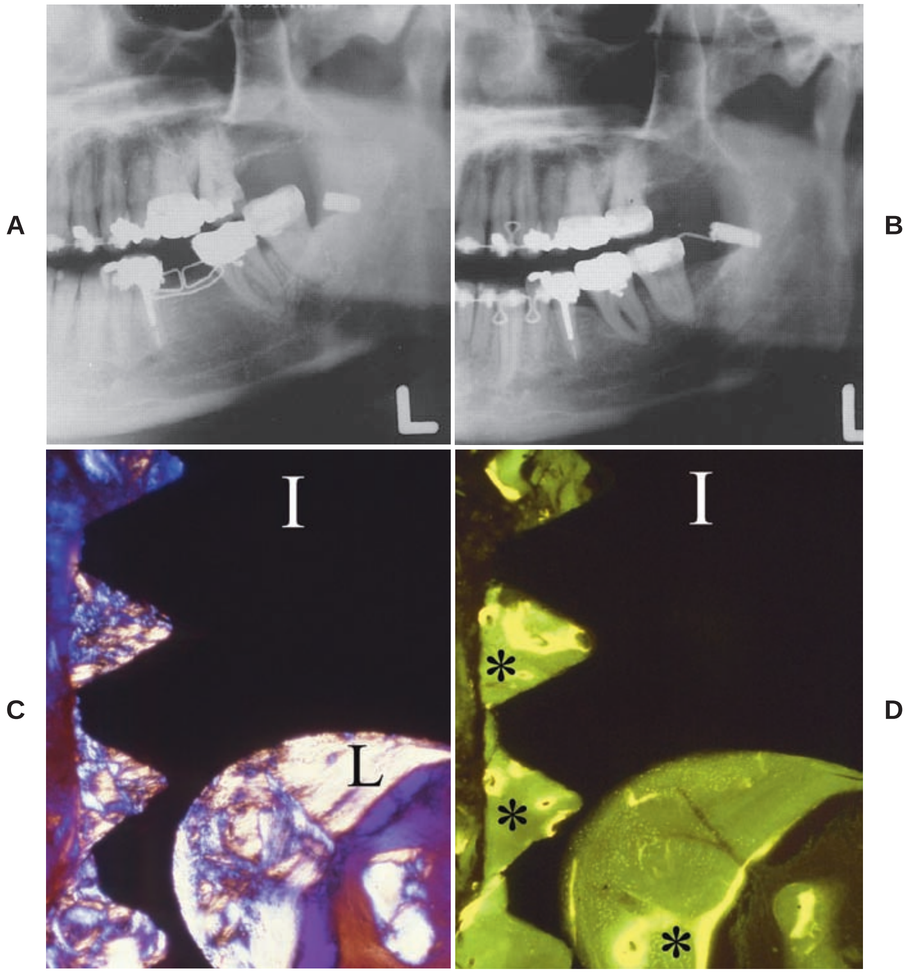


FIGURE 10-85 **A,** Panoramic radiograph of the initial buccal alignment before an implant is uncovered. **B,** Panoramic radiograph of the closed extraction site. **C,** Polarized light microscopy of lamellar bone (*L*) around the implant (*I*) recovered after completion of treatment. **D,** Two demeclocycline labels (*) in bone adjacent to the implant (*I*) document the high rate of bone remodeling that apparently is the mechanism for long-term maintenance of rigid osseous fixation (osseointegration). *(From Roberts WE, Marshall KJ, Mozsary PG: Rigid endosseous implant utilized as anchorage to protract molars and close on atrophic extraction site,* Angle Orthod *60:135, 1990.)*

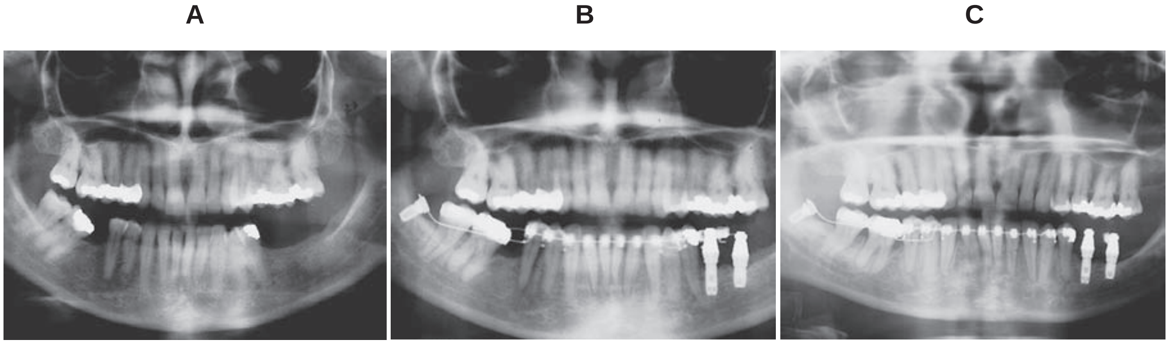


FIGURE 10-86 A 44-year-old woman has a partly edentulous mandibular arch and a long history of temporomandibular dysfunction and pain. **A,** A progress radiograph shows restoration of occlusion in the left mandibular buccal segment with implants. **B,** The molars on the right side are being intruded and rotated mesially with the retromolar implant anchorage mechanism. **C,** By the end of active treatment, the mandibular curve of Spee has flattened and ideal alignment of the residual dentition has been achieved. *(From Epker BN, Stella JP, Fish LC:* Dentofacial deformities: integrated orthodontic and surgical correction, *ed 2, vol 4, St Louis, 1999, Mosby.)*

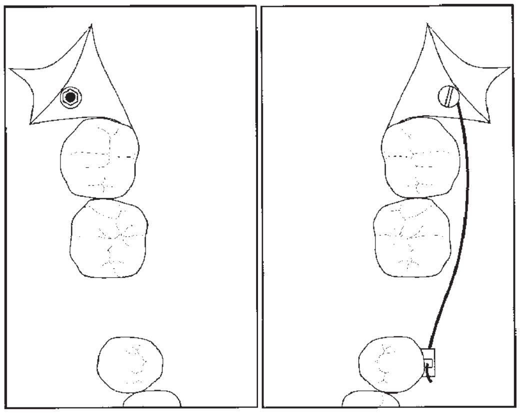


FIGURE 10-87 The drawing on the *left* shows the soft tissue flap design for placing a retromolar anchorage implant distal to a mandibular right third molar. The drawing on the *right* illustrates the attachment of the 0.019- × 0.025-inch titanium-molybdenum alloy wire to the implant with a standard cover screw. Note that the free end of the passive anchorage wire is inserted into the vertical slot of a bracket bonded to the buccal surface of a mandibular left second premolar. *(From Epker BN, Stella JP, Fish LC:* Dentofacial deformities: integrated orthodontic and surgical correction, *ed 2, vol 4, St Louis, 1999, Mosby.)*

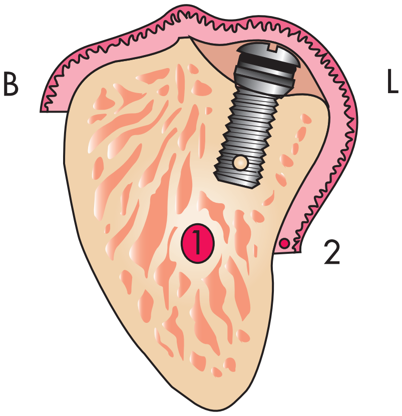


FIGURE 10-88 A cross section of the mandible distal to the third molar shows that the retromolar implant is inclined buccally (*B*). Using the shelf of bone on the lingual (*L*), the 7- to 10-mm implant is oriented toward the inferior alveolar nerve (*1*) and away from the lingual nerve (*2*). *(Redrawn from Epker BN, Stella JP, Fish LC:* Dentofacial deformities: integrated orthodontic and surgical correction, *ed 2, vol 4, St Louis, 1999, Mosby.)*

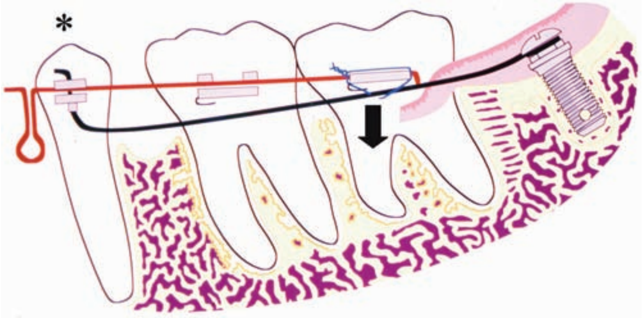


FIGURE 10-89 A schematic drawing of the implant anchorage mechanism shows an internal abutment (i.e., the titanium-molybdenum alloy anchorage wire) attached to the endosseous base with the cover screw (healing cap). The anchorage wire passes through the mucosa in the depth of the buccal fold on the buccal aspect of the terminal molar. Extrusion of the molars during axial alignment and space closure is controlled by the intrusive force (*arrow*) generated by ligating the molar bracket to the anchorage wire with a steel ligature. Sagittal anchorage for mesial movement of the molars is achieved by inserting the passive anchorage wire into the vertical tube of a bracket anterior to the extraction site (*). To achieve unidirectional space closure, the keyhole vertical loop is activated by pulling the archwire at the distal of the terminal molar and bending it down. *(Redrawn from Epker BN, Stella JP, Fish LC:* Dentofacial deformities: integrated orthodontic and surgical correction, *ed 2, vol 4, St Louis, 1999, Mosby.)*

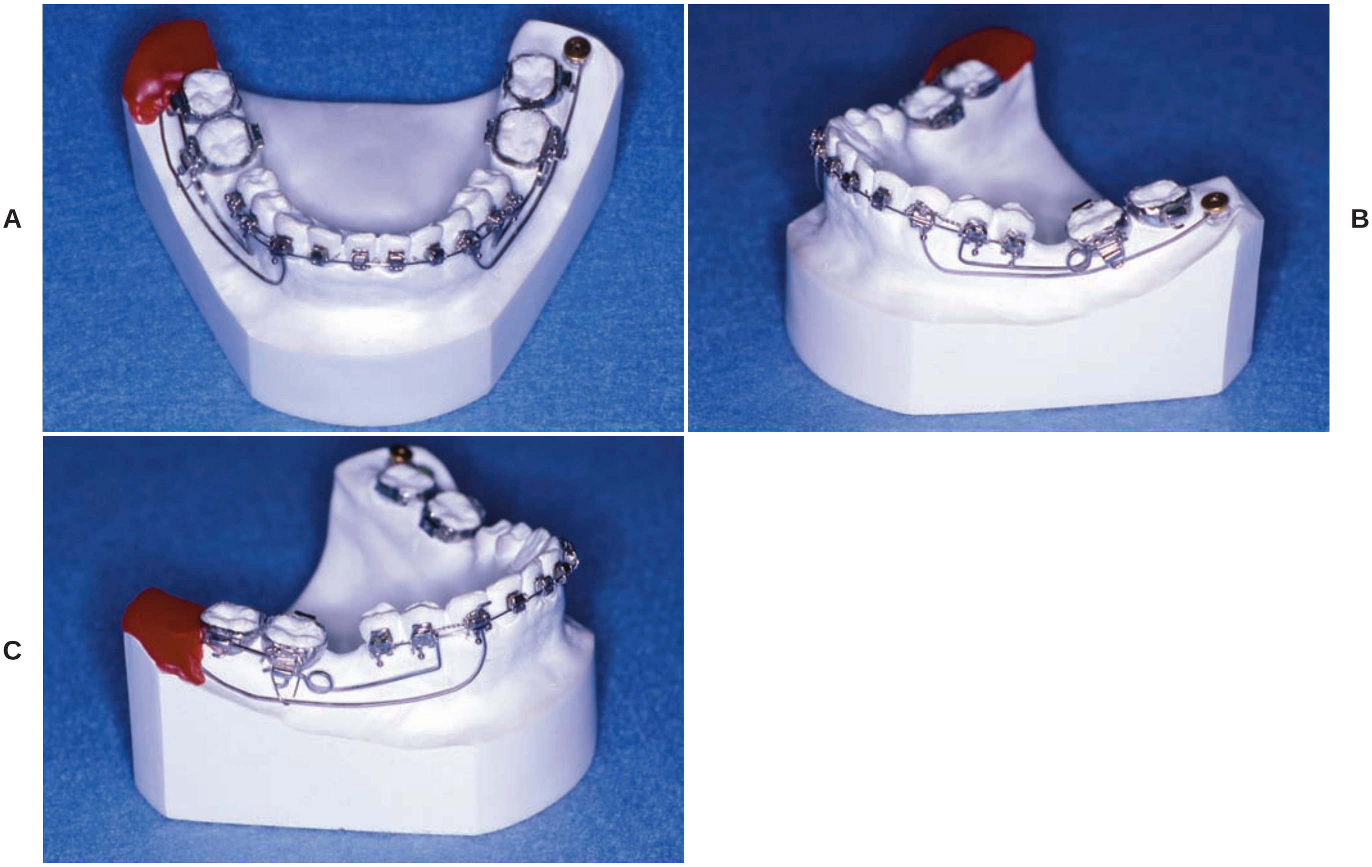


FIGURE 10-90 **A,** A mock-up demonstrates retromolar implant anchorage. Orthodontic mechanics are designed to align mandibular second and third molars and close the edentulous spaces by translating the molars mesially. The left retromolar implant shows the relationship of the fixture to supporting bone (surgical view). The right implant is covered with wax to simulate the closure of soft tissue over the implant with the titanium-molybdenum alloy anchorage wire attached. **B,** Mechanics are shown for mesial root movement of the second molar into the first molar extraction site. Note that the mesial arm on the root spring is immediately adjacent to the first premolar bracket to prevent the second molar from moving distally as it is positioned upright. To prevent space from opening mesial to the first premolar, a steel ligature (rope tie) connects the first premolar to the canine. A steel ligature connecting the bracket of the second molar to the titanium-molybdenum alloy anchorage wire controls molar extrusion. **C,** Similar mechanics as shown in B are used for simultaneous alignment of both molars. A rectangular arch wire segment connects the two molars. Extrusion is controlled by tying the second molar to the anchorage wire with a steel ligature.

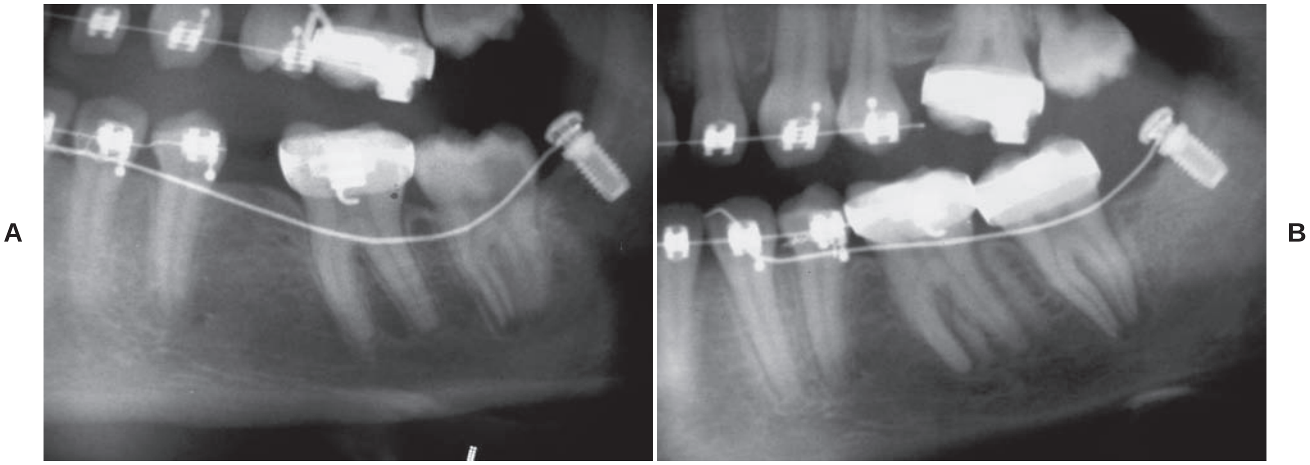


FIGURE 10-91 **A,** A postoperative panoramic radiograph reveals a retromolar implant to be used for indirect anchorage to close the space caused by a missing second premolar in an 11-year-old girl. Note that the anchorage wire is positioned too far apically. **B,** A panoramic radiograph shows the rapid space closure associated with mesial movement of the molars. Note the anchorage wire has been repositioned just under the molar brackets to lessen soft tissue irritation.

Mini-implants for Orthodontic Anchorage. Kanomi[165] introduced a series of mini-screws as miniature implants for orthodontic anchorage. Although some of the non-integrated titanium screws served as adequate anchorage units, some loosened and failed during treatment. A new series of osseointegrated miniimplants was developed and tested in animals.[166] Deguchi et al.[167] found that 97% of 96 implants placed in eight dogs successfully integrated and 100% of the implants that achieved osseointegration were successful as anchorage units. For a review of the bone physiology of mini-screws and miniiplants used for orthodontics anchorage, see Roberts WE, Roberts JA. Endosseous miniscrews: historical, vascular and integration perspectives, and Roberts WE, Kanomi R. Miniature osseointegrated implants for orthodontics anchorage. In Nanda RA, editor: *Temporary anchorage devices in orthodontics,* St. Louis, Mosby Elsevier, 2009.

SUMMARY

Bone physiologic, metabolic, and cell kinetic concepts have important clinical applications in orthodontics and dentofacial orthopedics. The application of fundamental concepts is limited only by the knowledge and imagination of the clinician. Modern clinical practice is characterized by a continual evolution of methods based on fundamental and applied research.

Acknowledgments

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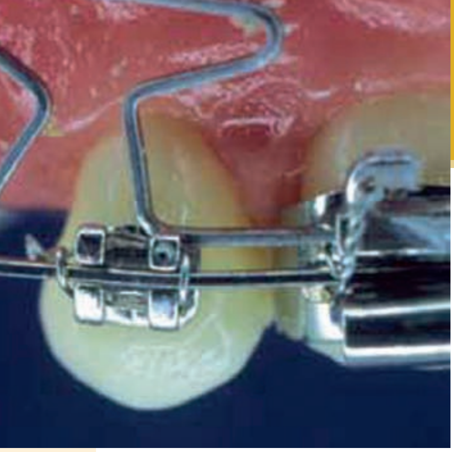

CHAPTER 11

Application of Bioengineering to Clinical Orthodontics

Charles J. Burstone

OUTLINE

Sign Conventions
Biomechanics of Tooth Movement
  Centers of Rotation
  Force Magnitude and the Rate of Tooth Movement
  Relationship of Force Magnitude to Pain and Tooth Mobility
  Optimal Force and Stress
The Orthodontic Appliance
  Active and Reactive Members
    Moment-to-Force Ratio
    Load-Deflection Rate
    Maximal Elastic Moment
  Manner of Loading
  Mechanical Properties of Metals
    Basic Behavior of Alloys
    Elastic Limit
    Modulus of Elasticity
    Shape Memory Alloys
    Ideal Orthodontic Alloys
  Wire Cross Section
  Selection of Proper Wire (Alloy and Cross Section)
  Wire Length
  Amount of wire
  Stress Raisers
  Sections of Maximal Stress
  Direction of Loading
  Attachment
  Forces from a Continuous Arch
  Principles of Spring Design
  Fiber-Reinforced Composite Applications
  The Role of Friction
Summary

An important aspect of the scientific revolution that has taken place in biology over the past decade is the broad application of the physical sciences to living tissues. Physics, engineering, and mathematics can be applied similarly, with great profit to the field of orthodontics. Of all the possible applications, this chapter concerns itself with only one, the biophysics of the orthodontic appliance. The chapter covers whether theoretic mechanics can help in the design and clinical manipulation of an orthodontic appliance.

Theoretic mechanics offers potential benefit in orthodontics in three primary ways:

- Basic principles of engineering and physics can point the way toward improved design of orthodontic appliances. If the orthodontic specialty relies only on trial-and-error procedures for the development of new appliances, the developmental horizons become sharply limited. Empiricism in orthodontic design must give way to a new discipline of orderly appliance development using concepts from the physical sciences. In a less ambitious way, theoretic mechanics may help in the design of a new appliance by enabling clinicians to apply knowledge that has been gained from some of the older appliances. For example, if an existing appliance works well for a given type of tooth movement, clinicians can use the force system developed by that appliance as a basis for designing a new one. Although the trial-and-error method has proved valuable in the past, presumably the application of biophysical principles will give rise to a more orderly development of orthodontic appliances.
- Study of the biophysics of tooth movement can yield important information. If researchers and clinicians can quantify the force systems applied to teeth, they can understand clinical, tissue, and cellular responses better. To make valid judgments about the response of teeth to orthodontic forces, clinicians first must define fully the force system acting on the tooth. Theoretic mechanics also can be helpful in formulating useful concepts of stress distribution in the periodontal ligament (PDL) as it relates to bone remodeling.
- A knowledge of physics can enable better treatment results. Each time clinicians adjust an arch wire or any other orthodontic appliance, they make certain assumptions about the relationship between the appliance and the biology of tooth movement. As

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these assumptions about the relationship between forces and tooth movement come closer to reality, the quality of orthodontic treatment will improve. For instance, many of the undesirable side effects that occur during orthodontic treatment can be attributed directly to a lack of understanding of the physics involved in a given adjustment. Many variables in orthodontic treatment cannot be controlled fully, such as growth and tissue response to appliances; however, the force placed on the tooth is a controllable variable. In a sense, clinicians have the duty to understand the physics of these forces so they can better control the one variable they are in a position to affect so strongly.[1,2]

SIGN CONVENTIONS

A universal sign convention is available for forces and moments in dentistry and orthodontics. The convention is as follows: Anterior forces are positive (+), and posterior forces are negative (–); lateral forces are positive (+), and medial forces are negative (–) (Figure 11-1). Forces acting in a mesial direction are positive (+); forces acting in a distal direction are negative (–). Buccal forces are positive (+); lingual forces are negative (–) (Figure 11-2).

Moments (couples) that tend to produce mesial, buccal, or labial crown movement are positive (+), and moments that tend to produce distal or lingual crown movement are negative (–) (Figure 11-2, *B, C*). The same convention is used for groups of teeth (a segment or an entire arch) and for establishing signs for orthopedic effects on the maxilla and mandible. However; any sign convention is acceptable if it is made clear to the reader by diagram.

BIOMECHANICS OF TOOTH MOVEMENT

From a clinical viewpoint, two major problems related to tooth movement can be considered: (1) the type of force system required to produce a given center of rotation and (2) the optimal force magnitudes for tooth movement. Solving these problems requires a thorough understanding of the forces and moments that may act on the teeth and detailed documentation of tooth movement and the response in the PDL.

The forces delivered by an orthodontic appliance can be determined by direct measurement with suitable instruments or, partly, by mathematical calculation.[3–6] The load-deflection rates of orthodontic springs or wires can be measured with electronic strain gauges or mechanical gauges. Most orthodontic appliances deliver a complicated set of forces and moments. In clinical studies, therefore, appliances of simple construction, in which forces are determined more easily and accurately, are useful. For the same reason, a clinical study in which force variables are controlled is likely to yield more information than are data taken from patients in a routine orthodontic practice.

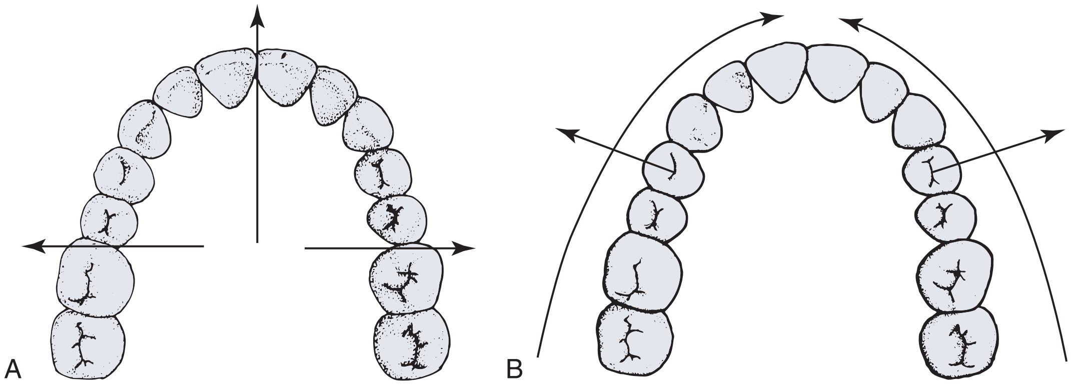

FIGURE 11-1 Sign conventions. **A,** Lateral and anterior forces are positive. **B,** Buccal, labial, and mesial forces are positive. *(From Burstone CJ, Koenig HA: Am J Orthod 65:270, 1974. With permission from the American Association of Orthodontists.)*

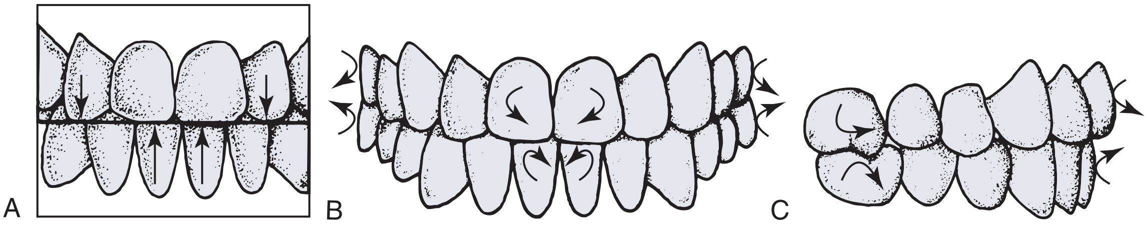

FIGURE 11-2 Sign conventions. **A,** Extrusive forces are positive. **B, C,** Moments (couples) that tend to move crowns in a mesial, buccal, or labial direction are positive. *(From Burstone CJ, Koenig HA: Am J Orthod 65:270, 1974. With permission from the American Association of Orthodontists.)*

The problems inherent in studying the response of a tooth subjected to a force system are much more complex and difficult to solve than those of simple measurement of the forces. Observations can be made on three levels to describe the response of a tooth to forces: the clinical level, the cellular and biochemical level, and the stress-strain level. The clinical level allows the study of phenomena such as the rate of tooth movement, pain response, tooth mobility, alveolar bone loss, and root resorption. The cellular and biochemical level gives insight into the dynamics of bone and connective tissue changes in the PDL.[7,8]

Perhaps the most important and least understood level is the stress-strain level of activity in the PDL. The ability to determine accurately the level of stress (the force per unit area) in different areas of the PDL may well offer the best means of correlating the application of force on a tooth with the response of the tooth. Currently, to place strain gauges in the PDL to measure stress distributions is impossible; therefore, knowledge of stress phenomena must depend on another approach. For example, a mathematic model of the tooth and surrounding structures can be constructed based on certain assumptions, and theoretic stress levels can be calculated from these models if the forces applied to the teeth are known. Unfortunately, these mathematic models are no better than the assumptions on which they are based. All such calculations therefore should be verified by clinical or animal experimentation whenever possible.

Centers of Rotation

Tooth movement often is described in general terms: tipping, bodily movement, and root movement. More specific descriptions can be devised by locating a center of rotation relative to three mutually perpendicular planes, which are (1) a buccolingual or labiolingual plane oriented through the long axis of the tooth, (2) a mesiodistal plane also oriented through the long axis of the tooth, and (3) a transverse plane that intersects the buccolingual or labiolingual and mesiodistal planes at right angles. To define fully the changes in the position of a tooth, one must use all three planes of reference. For simplicity's sake, the following discussion considers two-dimensional representations of teeth, and therefore only one plane of space is described. If certain simple assumptions are made about stress distributions (e.g., a uniformly varying distribution for pure rotation and a uniform distribution for pure translation), if a linear stress-strain relationship is postulated, and if axial loading is ignored, to predict mathematically the force system required for various centers of rotation is possible. These calculations will err because the realities of tooth and PDL differ from idealized assumptions. A typical central incisor is used to represent the application of this theory to centers of rotation. For purposes of presentation, actual force values are not used.

As a tooth translates (bodily movement), a relatively uniform stress distribution along the root is found. In terms of a center of rotation, the center of rotation for translation is at infinity (Figure 11-3, *A*). A single force acting through the center of resistance of a root effects pure translation of a tooth. The center of resistance in a single rooted tooth with a parabolic shape is calculated by multiplying the distance from the alveolar crest to the apex by 0.33. The center of resistance coincides with the centroid, which in this case is the geometric center of the part of the root between the alveolar crest and the apex. A force placed near the center of the root therefore should produce pure translation.[9,10]

If a pure moment (a couple) is placed anywhere on a tooth, a center of rotation is created near the center of resistance of the tooth. In Figure 11-3, *B*, the clockwise moment tends to displace the crown in a lingual direction and the root in a labial direction, with a center of rotation near the middle of the root. Unlike pure translation, pure rotation does not produce a uniform stress distribution in the PDL, but rather a uniformly varying distribution, with the highest stress at the apex and the next highest at the alveolar crest. No stress is found at the center of resistance. The center of rotation is located at the level of the root where the stress is zero.

Pure translation (center of rotation at infinity) and pure rotation (center of rotation near the center of resistance) can be considered the two basic types of tooth displacement. Other centers are a combination of pure rotation and pure translation; that is, any center of rotation can be produced by combining a single force through the center of resistance of a root and a pure moment if the proper force-to-couple ratio is used.[11]

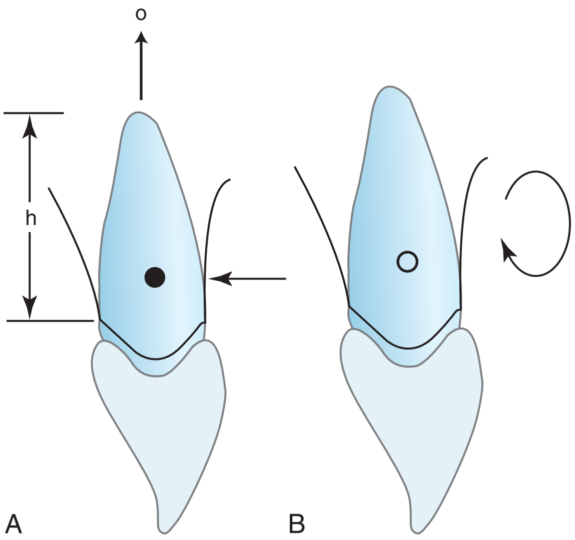

FIGURE 11-3 Basic tooth movements. **A,** A force acting through the center of resistance of a tooth produces translation-center of rotation at infinity. **B,** A couple acting on the tooth produces a center of rotation at the center of resistance.

In Figure 11-4, *A*, a lingual force is acting through the center of resistance of the tooth. If a couple is added in a clockwise direction, the center of rotation moves from infinity toward the center of resistance. If the magnitude of the couple is small (relative to the force at the center of resistance), the center of rotation lies at the apex of the root. As the magnitude of the couple increases, the center of rotation shifts from the apex toward the center of resistance; finally, as the couple continues to increase, the center approaches the center of resistance of the tooth. The relative magnitude of the couple and force acting through the center of resistance determines the specific type of lingual tipping of the tooth if the direction of the moment is clockwise.

However, a counterclockwise moment plus a force acting through the center of resistance places the center of rotation somewhere between the center of resistance and infinity (Figure 11-4, *B*). More specifically, as the couple-to-force ratio increases, the center of rotation moves from the incisal edge to the level of the bracket and finally approaches the center of resistance. Control of the center of rotation during tooth movement then is based on two components: placement of a single force through the center of resistance of the tooth and use of a couple of proper direction and magnitude.[12]

In most instances, however, anatomic limitations in the oral cavity make placing a force through the center of resistance impractical. Therefore, a force system must be placed on the crown of the tooth (at a bracket or tube) equivalent to the required couple and force acting through the center of resistance. The two force systems are equivalent if the sums of their individual forces (F_x, F_y, and F_z) are equal and the sums of their moments around any axis of rotation are equal.

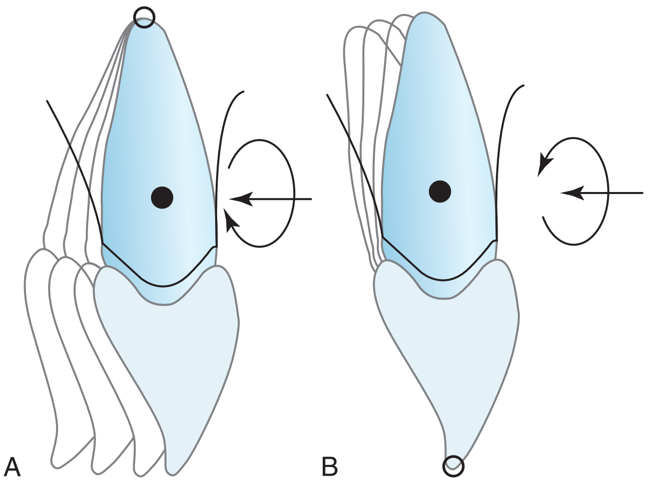

FIGURE 11-4 A couple and a force acting through the center of resistance. **A,** A negative couple produces lingual tipping of the incisor crown. **B,** A positive couple produces incisor lingual root movement.

The following equivalent force systems, acting on a bracket of an incisor, are typical effects of changing the couple-to-force ratio:

- A lingually directed single force placed on the crown of a tooth produces a center of rotation somewhere between the center of resistance and the apex (Figure 11-5, *A*).
- If a counterclockwise moment (lingual root torque) of sufficient magnitude is added, the center of rotation moves to the apex (Figure 11-5, *B*).
- If an additional moment in the same direction is placed on the tooth, the center of rotation moves toward infinity, and at this instance the tooth is translating, or moving bodily (Figure 11-5, *C*).
- Further increases in the magnitude of the couple place the center of rotation incisal to the crown of the tooth (Figure 11-5, *D*), then at the incisal edge, and finally at the bracket.

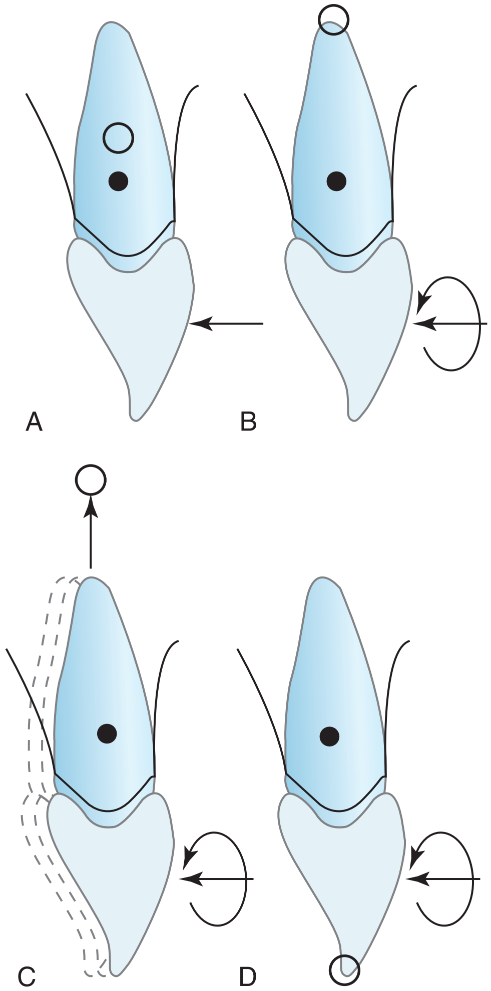

FIGURE 11-5 A single force acting on the crown of a tooth produces a center of rotation (*open circle*) slightly below the center of resistance. **A,** If increasingly larger couples are added to the force in the direction shown in **B** to **D,** the center of rotation will be found at the apex **(B),** the infinity **(C),** or the incisal edge **(D).**

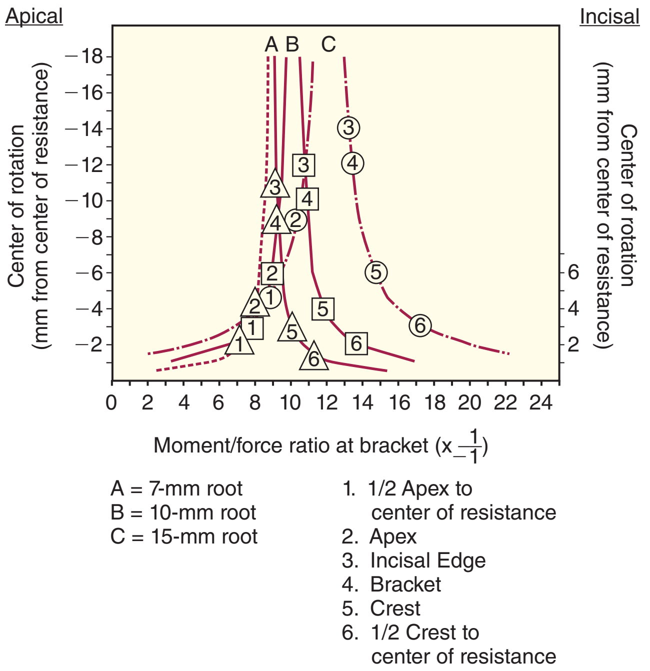

FIGURE 11-6 Moment-to-force ratio plotted against the center of rotation for three incisor root lengths. Note that identical moment/force values produce different centers of rotation if the root length varies.

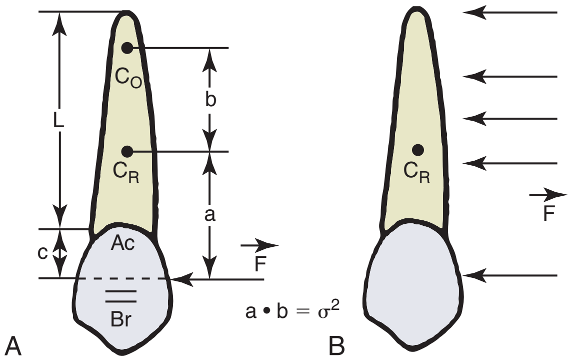

FIGURE 11-7 **A,** A general theory of tooth movement states that the product of the distances a times b equals s^2. **B,** s^2 is a constant provided the single forces are parallel and act in the same plane. Any of the individual forces shown in B produces the same s^2. *(Redrawn from Nägerl H, Burstone CJ, et al:* Am J Orthod *49:337, 1991.)*

- Any further increase in the moment tends to move the center of rotation toward the center of resistance.

In Figure 11-6 the moment-to-force (M/F) ratio is plotted against the center of rotation for incisor roots of 7 mm, 10 mm, and 15 mm. The moment and force are applied at the bracket. In all cases the distance of the bracket is 6 mm from the alveolar crest. The direction of the force applied to the incisor is lingual (–), and the sense of the moment is lingual root torque (+). As the M/F ratio approaches zero in the three examples, the center of rotation approaches the center of resistance. As the ratio increases the center of rotation is found at the apex of the root, at infinity, at the incisal edge, at the bracket, and at the alveolar crest. As the ratio becomes infinitely large, the center of rotation approaches the center of resistance. A slight variation in the M/F ratio can make a significant difference in the positioning of the center of rotation, except with ratios that produce centers of rotation near the center of resistance. Furthermore, the same M/F ratio produces different centers of rotation, depending on the length of the root.

Nägerl et al.[13–15] developed a general theory of tooth movement based on assumptions about three-dimensional linear elasticity. The general theory states that in any given plane, the distance from the applied force to the center of resistance (a) multiplied by the distance from the center of resistance to the center of rotation (b) equals a constant (s^2), which represents the distribution of the restraining forces in the PDL. As shown in Figure 11-7, regardless of where the force is applied in a given plane, s^2 remains the same. Experimental determination of s^2 offers the possibility of determining centers of rotation for given teeth with similar morphologic characteristics, which should minimize the number of recordings required experimentally.

The preceding analyses have a number of clinical implications:

1. The location of the center of rotation depends on the ratio between the moment and the force applied to the tooth (M/F ratio) and not on the absolute value of either. For example, if a single force is placed on the crown of a tooth, the center of rotation should be the same, regardless of the magnitude of the force. A light or a heavy force tends equally to move the crown in one direction and the root in the other. This is in sharp contrast to the oft-repeated idea that lighter forces do not displace root apices as much as heavy forces. This statement would be accurate only if a properly directed moment, as well as a force, were applied to the tooth in question. If the moments were identical, the tooth with the lower force would possibly have minimal root displacement.[16] Research suggests that if identical M/F ratios are delivered to a tooth, the center of rotation may not be exactly identical. Heavier single forces on the crown tend to move the center of rotation slightly apically rather than occlusally.
2. The M/F ratio is crucial to the establishment of a center of rotation. Small miscalculations in this ratio can change the type of tooth movement effected. Because stress distributions in the PDL are altered as well, the ease of tooth movement also may be affected.
3. The load-deflection rate of the force acting on the crown and the torque deflection (angular) rate of the moment often may be different. For example, if a

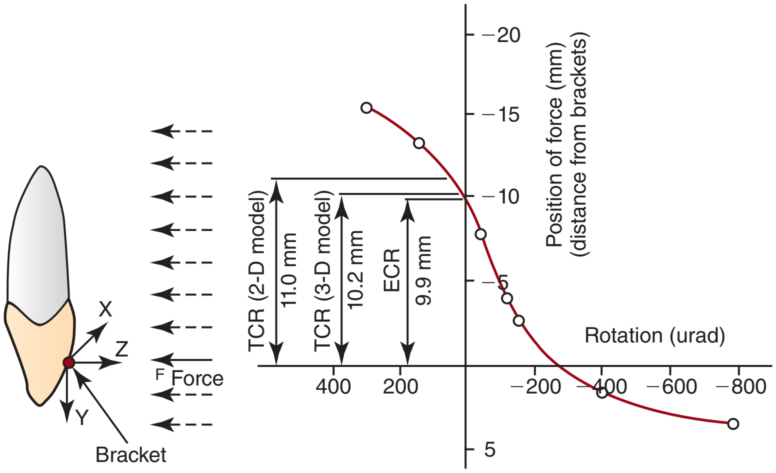

FIGURE 11-8 Center of rotation measured from the centroid of the paraboloid of revolution (h/3) as a function of the moment-to-force ratio at the bracket. The center of rotation approaches infinity as the line of action of the applied force approaches the centroid. *TCR,* Theoretic center of resistance; *ECR,* experimental center of resistance.

> lingual force dissipates faster than the moment (torque), the center of rotation changes. In this case the center of rotation shifts, rather than remaining constant, because of the change in the M/F ratio.

Laser holography is a new, noninvasive technique for studying tooth movement in closer detail.[9,10,17,18] In Figure 11-8, the location of the center of rotation is plotted against the M/F ratio for a typical maxillary central incisor. The experimental curves are similar to those derived from previously discussed theory.

In addition to analytic methodology and laser holography, numeric techniques have been used to determine centers of rotation under different loading conditions and estimate stress in the PDL. These techniques use a three-dimensional finite element method. The tooth and the alveolar process are broken down into elements (Figure 11-9) by accurately determining the shape of the elements and the constitutive mechanical behavior of each element. Centers of rotation are determined using assumed forces on the teeth.[19–22]

As researchers become more knowledgeable, refinements in mathematic models will provide the clinician with good estimates of the M/F ratios needed to produce required centers of rotation for teeth of different geometric configurations and periodontal supports and for groups of teeth or segments.

The lack of knowledge about the variation in tooth morphology and support should not deter clinicians from making their best estimates of the relationship between the forces exerted by an appliance and the centers of rotation produced. An understanding of basic theory can guide the clinician in adjusting appliances when undesirable centers of rotation result.

Nägerl et al.[13,14] developed a concept of tooth motion that is not as limiting in three-dimensional space as the center of rotation concept. Tooth movement is envisioned as a screw oriented in a coordinate system. The screw forms an axis around which the tooth rotates, and translation may occur in or out along that axis.

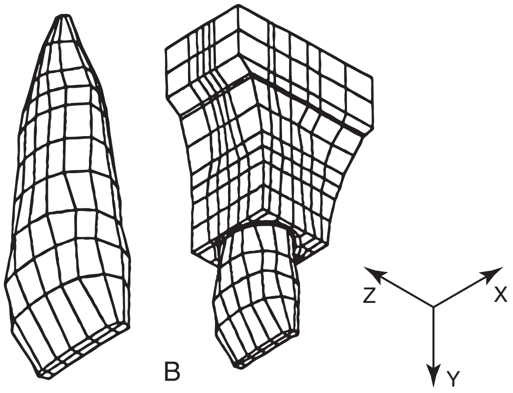

FIGURE 11-9 Three-dimensional model for tooth **(A)** and tooth-periodontal ligament-alveolar bone system **(B).** *(Redrawn from Tanne K, Koenig HA, Burstone CJ: Moment to force ratios and the center of rotation,* Am J Orthod Dentofac Orthop *94(5)426–431, 1988.)*

Force Magnitude and the Rate of Tooth Movement

Considerable debate in orthodontics has centered on the relationship of force magnitude and the rate of tooth movement.[23–27] Attempts at correlations of this type are more likely to succeed if the rate of tooth displacement is used rather than the total displacement (absolute displacement) value. The rate of tooth movement is defined as the displacement of a tooth per unit time, and it usually is measured in millimeters per hour, per day, or per week. As the increments of time become shorter, the dynamics of tooth movement become clearer, and thus daily rather than weekly or monthly recordings are preferred.

The average daily rate can be established by dividing the absolute displacement by the number of days when measurements are made at less frequent intervals than daily. Such methods tend to smooth out rate curves and eliminate much of the rate fluctuation that can be observed each day. For practical purposes, if daily increments of movement cannot be measured (which is the case in many clinical studies), average rates of tooth movement must be used. However, when average rates are used, their limitations should always be kept in mind.

Two possible force-rate relationships can be studied. One approach relates force magnitude and tooth displacement. The other approach, which perhaps is more logical, attempts to relate stress-strain phenomena in the PDL (force per unit area and displacement per unit length) with tooth displacement. Until better experimental methods are devised, the latter method is limited by the fact that the stress-strain values must be calculated from mathematic models rather than obtained by experimentation in the living.

The difficulty of correlating forces and tooth movement is compounded by the large number of variables that can influence the recorded rate of tooth displacement. Connective tissue forces operating through gingival and transseptal fibers or forces from the tongue, perioral musculature, and muscles of mastication may alter the force system acting on the tooth. For these reasons the clinican should be aware of certain limitations in predicting tooth movement. If a relatively constant force is placed on a tooth, a typical type of graph is obtained when the rate of tooth movement is plotted against time (Figure 11-10). Tooth movement can be differentiated into three phases: initial phase, lag phase, and post lag phase. The initial phase, which is characterized by a period of rapid tooth movement, normally lasts a few days. The onset of displacement immediately after application of a force and its rapidity suggest that tooth movement in the initial phase largely represents displacement of the tooth in the periodontal space. The initial phase is followed immediately by the lag phase, during which the tooth does not move or shows a relatively low rate of displacement. A number of explanations have been postulated for the presence of a lag period. Some have suggested that the lag is caused by nonvitalization (hyalinization) of the PDL in areas of maximal stress and that no tooth movement can occur until the area of nonvitalization has been removed by cellular processes.[25,28,29] Others believe that the lag period may represent the interval required for absorption of the thicker compact bone of the lamina dura; hence the rate of tooth movement is reduced. The third phase of tooth movement, the post lag phase, occurs when the rate of tooth movement gradually or suddenly increases (see Chapters 5 and 6).

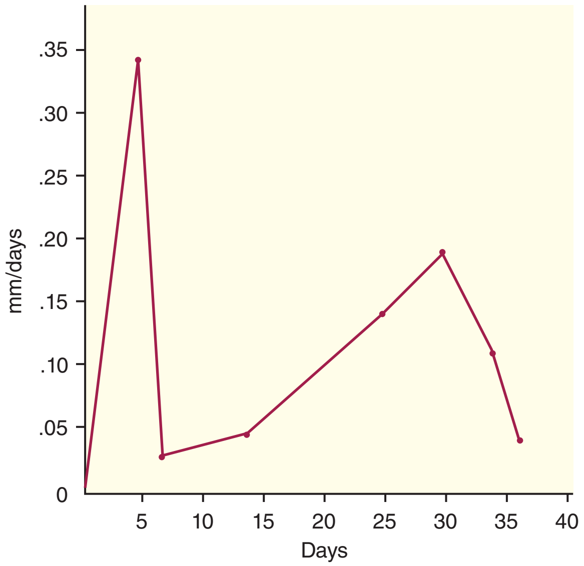

FIGURE 11-10 Typical tooth movement graph in which the rate of movement is plotted against the number of days after application of a continuous force (125 *g*). Rates are given for the reciprocal closure of a diastema between two central incisors.

The great variation of response in tooth movement to relatively identical force systems is impressive. However, this is not surprising because the force applied to a tooth is but one of many variables that determine its displacement. If constant force were applied to a tooth, the tooth might be expected to move at a constant rate through the alveolar process. Nevertheless, clinical measurements show a lack of constancy in rate not only during the initial and lag phases but also during subsequent tooth movement.

The crucial issue in orthodontic therapy is the relationship between force magnitude and the rate of tooth movement. The most obvious and appealing relationship is a linear one, in which more force implies greater tooth movement. Nevertheless, appealing as the simplicity of this assumption might be, it does not correspond to the facts observed histologically and clinically in all phases of tooth movement.

During the first part of the initial phase, when the tooth is deflected through the periodontal space, something approaching a linear relationship may exist. As the stress levels in the PDL increase, a faster rate of tooth movement is expected. Thus a light force may take days to move a tooth through the width of the PDL, whereas a heavy force, such as a dental separator, can accomplish the same result in seconds. The responses to light and to heavy forces show no gross difference if the absolute displacement is measured after 2 or 3 days or if the average rate is calculated for a similar period.

In Figure 11-11, the average rates of tooth movement are plotted against the number of days after insertion of a continuous-force appliance. Application of 10 *g* and 200 *g* of force on a central incisor produces a similar

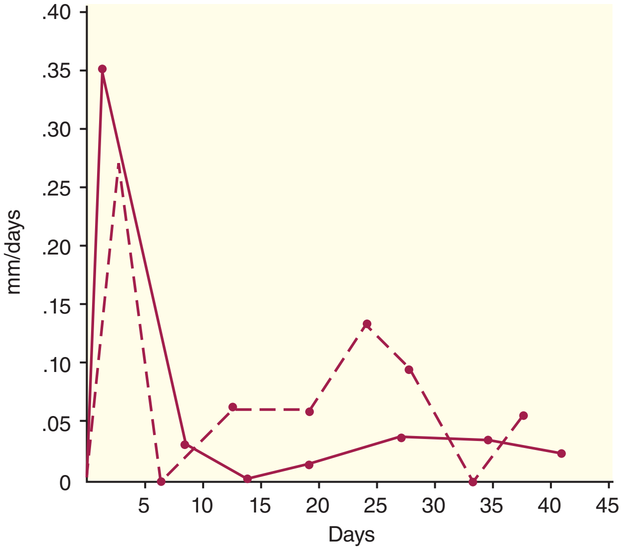

FIGURE 11-11 Rates of tooth movement with different force applications (*dotted line*, 200 *g*; *solid line*, 10 *g*). The rates given are for reciprocal closure of a diastema between two central incisors.

initial response. Fairly light forces apparently can move a tooth through a greater part of the width of the PDL. After this has been accomplished, higher forces may be expected to produce additional compression of the ligament. This additional compression is of lesser magnitude than the initial tooth movement and therefore is not evident in gross measurements of tooth movement. Variables such as the width of the PDL are much more important than force magnitude in determining the initial absolute displacement of a tooth.

During the lag phase of tooth movement, two processes can be observed in areas of pressure: direct resorption may occur on the bone surface facing the root, or indirect (undermining) resorption may start in the medullary spaces and work toward the tooth.[28,29] Currently, the best that can be hoped for is the development of a working hypothesis to explain and relate these bony changes to stress levels in the PDL. Until data are available to correlate measured or calculated stress levels with histologically observed bony resorption, assumptions of this type must be considered tentative. Theoretically, if low-level stress is introduced into the PDL, no bony transformation will occur. If the stress level is increased, a point will be reached at which bone resorption can begin (i.e., a threshold stress level). Nothing is known about the level of stress that can initiate bone resorption and apposition. Clinically, however, relatively small force magnitudes (e.g., 10 *g* or less on the maxillary incisors) can tip teeth.[30] If it even exists, the threshold force (the lowest possible force that will move a tooth) has a low magnitude, at least for simple tipping movements. Stress in the PDL above the threshold level can be expected to increase the amount of frontal resorption on the alveolar process. As the stress value increases, cellular activity can be expected to decline because areas of maximal stress undergo further compression of blood vessels and cellular elements. Histologically, these areas appear hyalinized and may be described as at least partly nonvital. Logically, then, bone resorption also declines because direct bone resorption requires vital connective tissue. Undermining resorption, however, is associated with high stress on the PDL and is a response to a compressed, nonvital area of connective tissue.

At a low stress level, little indirect resorption occurs; in fact, bone apposition can occur in the medullary spaces. As the stress increases, the magnitude of cellular response also increases; however, here, too, a limiting factor comes into play. A force can be only great enough to displace a tooth against the alveolar process; when this occurs, the stress level is limited, and for that particular interval no greater stimulus for indirect resorption may be expected.

Under most clinical conditions tooth displacement after the lag phase is caused by a combination of direct and indirect resorption. Concomitant bony and connective tissue changes in the areas of tension most likely occur following resorption of bone in the existing pressure regions.

What then is the relationship between force magnitude and the rate of tooth movement? At lower force magnitudes, most increases in force enhance the rate of tooth movement. At higher magnitudes, increases in force are partly responsible for hyalinization of the PDL and result in a longer lag phase. Eventually, undermining resorption removes the area of hyalinization, and the tooth moves rapidly into the newly created space. For these reasons, a wide range of forces, from light to heavy, can move teeth rapidly, provided the force is continuous.

Lighter forces are more likely to move teeth gradually; heavy forces produce a considerable lag phase followed by a period of rapid movement. Over a long interval, the average rate of movement for heavy continuous force may be greater than that seen with light continuous force. The complexity of the tissue changes and the large number of variables suggest that postulation of any simple relationship between force magnitude and the rate of tooth movement is plagued by inherent difficulties.

One of the variables to be considered in evaluating force magnitude and rate of movement is the type of tooth movement (center of rotation). For identical forces applied on the crown of a tooth, different centers of rotation can be obtained by altering the applied couple. Although the force remains the same, the change in the moment modifies the stress distribution in the PDL. Imagine a simple model of the tooth in its alveolus (a linear stress-strain relationship in the PDL is assumed). For simplicity's sake the model has a uniformly thick PDL and smooth alveolar walls. This oversimplifies the nature of the tooth and its surrounding structures; the

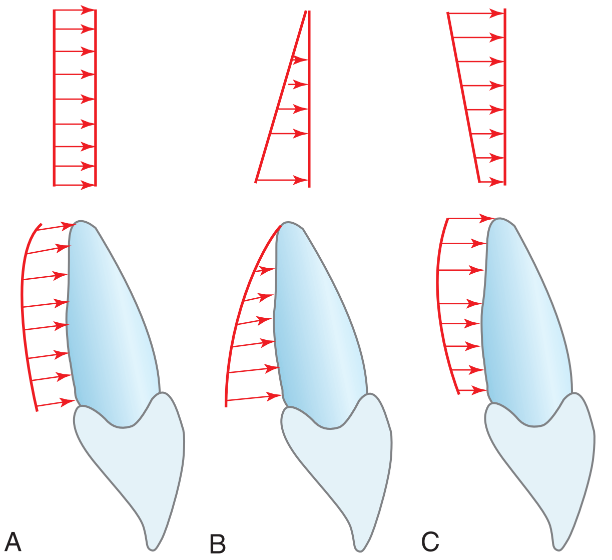

FIGURE 11-12 Theoretic stress distributions in the periodontal ligament. **A,** Translation. **B,** Center of rotation at the apex. **C,** Center of rotation at the incisal edge. The force magnitude is identical in the three situations.

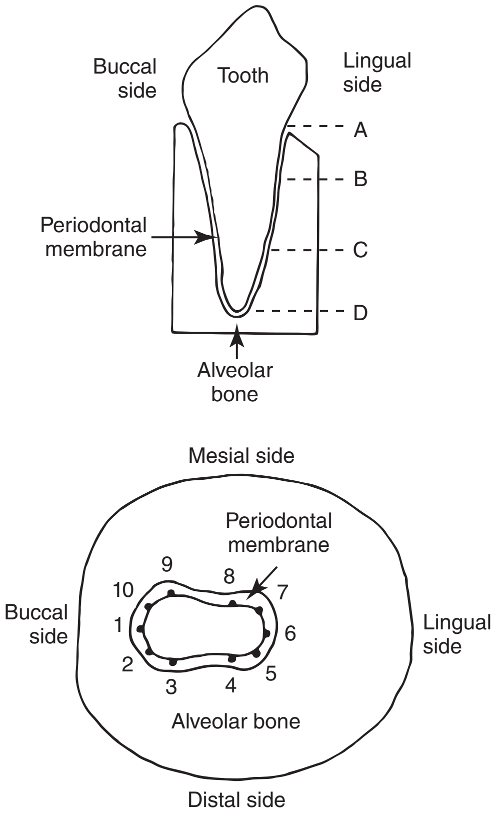

FIGURE 11-13 Occlusogingival levels *(A–D)* and horizontal points *(1–10)* where the principal stresses were determined. *(Redrawn from Tanne K, Sakuda M, Burstone CJ:* Am J Orthod Dentofac Orthop *92:499, 1987.)*

PDL is not uniformly thick, and the lamina dura is an irregular cribriform plate pierced by many holes. Nonetheless, the tooth model, despite all its difficulties, may prove most useful in comparing stress distribution for different types of tooth movement.

In pure translation (bodily tooth movement), a relatively uniform stress distribution is found in the PDL (actually, variations in the thickness of the PDL alter the stress distribution). Figure 11-12 shows an imaginary stress distribution for a force system causing translation of a central incisor in a lingual direction. If movement of the crown is reduced, the center of rotation shifts from infinity toward the apex of the root. Although the lingual force is identical with that used for bodily movement, the stress distribution is greatly changed. In tipping with a center of rotation at the apex, the maximal stress is found at the alveolar crest, and it is of considerably greater magnitude than that seen in translation. If the moment is increased beyond the amount required for translation, the center of rotation shifts from infinity toward the incisal edge. With the center of rotation at the incisal edge, a nonuniform stress distribution once again is observed. In this case the maximal stress is at the apex, and it is of greater magnitude than the stress found in translation. One should emphasize that in the three processes (translation, tipping at the apex, and rotation around the incisal edge), the lingual force is identical.

To develop the same maximal stress level of bodily tooth movement as that seen in rotation around the apex and the incisal edge, the lingual force and moment applied to the crown of the tooth must be increased. The center of rotation is an important factor that determines stress distribution in the PDL and hence the degree and type of cellular reaction. Therefore, in any attempt to relate force magnitude and the rate of tooth movement, the force system must be well defined. This requires knowledge not only of the magnitude but also of the constancy of all forces and moments acting on a tooth crown.

Figure 11-13 shows a tooth in which stress was studied using the finite element method. If a force is placed to produce translation, as shown in Figure 11-14, it is apparent that the stress is not as uniform as that described in the simplistic explanations given previously.[20,31–34] The simplistic explanations may aid in developing an understanding of the ways in which stress distributions vary with the same magnitude of force. One should remember, however, that a tooth is a three-dimensional, irregular body that has a most complicated stress distribution, even during translation.

Not all variables that influence the rate of movement involve stress levels in the PDL. Some involve the structure of the supporting bone of the alveolar process. Clinical observation also suggests a great variation in connective tissue response to the stress of orthodontic tooth movement. The response of tissues to mechanical

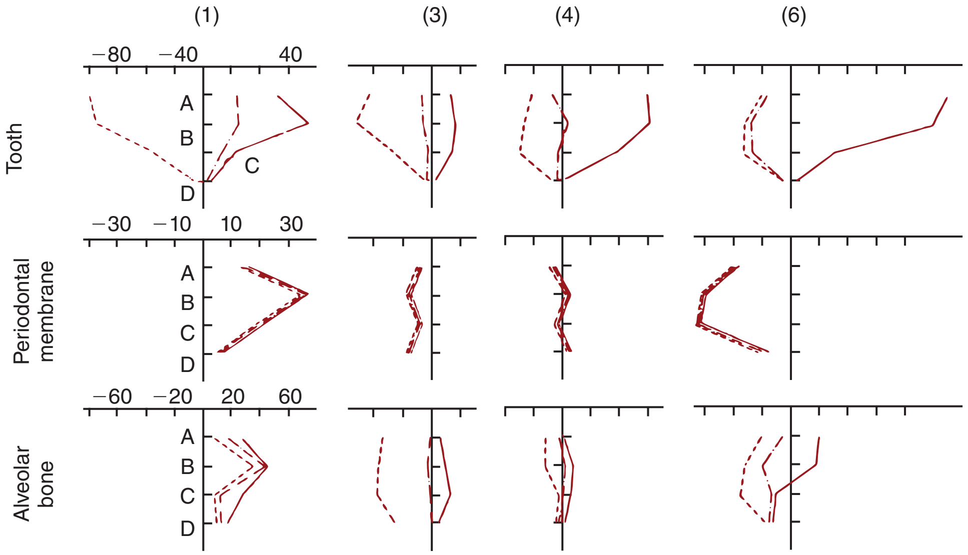

FIGURE 11-14 Stress distribution (g-cm^2) in loading condition for a lingual force of 100 g and a buccal crown couple of 858.5 g-mm (L$_2$). Three principal stresses—maximal (—), intermediate (-·-), and minimal (–)—are shown for four significant points (1, 3, 4, and 6) at various occlusogingival levels *(A–D). (Redrawn from Tanne K, Sakuda M, Burstone CJ:* Am J Orthod Dentofac Orthop *92:499, 1987.)*

stress is as yet obscure. However, the biochemical mechanisms by which stress and strain cause bone resorption and apposition are beginning to be better understood. Strain, working through biochemical mediators such as prostaglandins and piezoelectric effects, could be responsible for the biologic response to orthodontic forces.

Relationship of Force Magnitude to Pain and Tooth Mobility

After an active orthodontic appliance has been inserted, pain or discomfort may develop. Objective evaluation of pain is difficult because the pain response is determined by the central nervous system and local tissue changes. Not surprisingly, however, one finds a wide range of pain reactions among individuals in whom similar forces have been placed on the teeth.

To evaluate the relationship of force to pain, a classification of pain response is helpful. Three degrees of pain response may be described. First-degree pain is caused only by heavy pressure placed on the tooth with an instrument such as a band pusher or a force gauge. A first-degree response usually is elicited most easily by placing a force in the same direction as the force produced by the appliance. The patient is not aware of first-degree pain unless the teeth being moved with the orthodontic appliance happen to be manipulated. A second-degree pain response is characterized by pain or discomfort during clenching of the teeth or heavy biting. The patient still is able to masticate a normal diet without difficulty. If spontaneous pain is present or the patient is unable to masticate food of normal consistency, a third-degree response exists. Proper interpretation of pain data requires testing of the patient's response to heavy forces placed on the teeth before orthodontic treatment is begun. In this way the patient influences and even controls future pain and discomfort.

The two types of pain based on time of onset are immediate pain and delayed pain. Immediate pain responses are associated with sudden placement of heavy forces on a tooth. For example, a hard figure-eight tie between spaced incisors usually causes an acute pain reaction that gradually subsides. Some hours after an orthodontic adjustment, a delayed response may become evident. Delayed pain responses are caused by a variety of force values, from light to heavy, and represent hyperalgesia of the PDL. The degree of response usually lessens with time. A decreasing gradient is observed when, for instance, the pain reaction passes from a third-degree to a second-degree response and finally to a first-degree or zero-degree response. Although a gradient of this type usually is observed, situations arise in which the pain reaction suddenly increases, for no apparent reason, several days after a continuous force was applied.

Generally, the magnitude of force applied to a tooth has a definite correlation to the patient's experience of pain. Clinical studies have shown that the incidence of second- and third-degree pain is greater with application of heavier forces to the teeth. Not only is a greater degree of pain evident with a heavy force, but also the total number of days in which an abnormal pain response can be elicited is higher. This is not to imply, however, that a linear relationship exists.

The generalization that greater forces produce greater degrees of pain for longer periods is an oversimplification. As with the rate of tooth movement, force magnitude is only one of the factors determining the patient's final response.

An understanding of pain that occurs during orthodontic treatment also is obscured by a lack of knowledge about the reason pain is produced. This difficulty is aggravated by the fact that the PDL has no pain fibers. When the mechanisms of pain production during tooth movement become known, orthodontists will understand better the relationship of force and pain response.

Optimal Force and Stress

The effect of the couple-to-force ratio on the center of rotation of a moving tooth has been considered. Another question of great clinical significance concerns the appropriate magnitude of force and couple to achieve the most desirable response. In other words, what force magnitudes are optimal for tooth movement?[35–37]

From a clinical standpoint, an optimal force is one that produces a rapid rate of tooth movement without discomfort or ensuing tissue damage (particularly alveolar bone loss and root resorption) to the patient. From a histologic viewpoint, an optimal force is one that produces a stress level in the PDL that basically maintains the vitality of the tissue throughout its length and initiates a maximal cellular response (apposition and resorption). Optimal forces therefore produce direct resorption of the alveolar process. Because optimal forces require no period for repair, such forces apparently can be made to act continuously.

Histologic studies that correlate forces on the crown or stress in the PDL with tissue responses are most helpful in establishing the levels of optimal force for different situations. Unfortunately, the difficulty involved in obtaining human material is a limiting factor in this type of investigation. At the clinical level, where a greater wealth of material is available, the orthodontist is limited to gross tooth and bone changes or the patient's symptoms. This is not to imply that careful clinical observation is not helpful in determining optimal forces. Lack of pain, minimal mobility, and the absence of a considerable lag period immediately after appliance adjustment are clinical responses that suggest desirable stress levels in the PDL. To use the rate of tooth movement alone as an indicator of optimal force is dangerous, however. Rate is deceptive because heavy and light continuous forces can move teeth rapidly. It does not necessarily follow that because the teeth move rapidly, the forces used are optimal. Long-term histologic and clinical studies are needed to define further the nature of optimal force.

Although study of the biomechanics of tooth movement shows great promise, use of mathematic formulations to describe biologic phenomena is risky because mathematic oversimplification of highly dynamic, variable vital structures and reactions can mislead as well as inform. Biomechanical assumptions therefore must be checked against observations made on the clinical and histologic levels. This type of multidisciplinary approach offers the best hope for solving orthodontic problems involving force systems and tooth movement.

THE ORTHODONTIC APPLIANCE

In designing any orthodontic appliance, the orthodontist starts by subscribing to certain assumptions about the nature of an optimal force system to move teeth. An optimal force system is one that (1) accurately controls the center of rotation of the tooth during tooth movement, (2) produces optimal stress levels in the PDL, and (3) maintains a relatively constant level of stress as the tooth moves from one position to the next. For the sake of argument, assume that these objectives for the orthodontic appliance are correct; one then must decide what is needed to design an appliance to deliver this type of force system.

Active and Reactive Members

An orthodontic appliance can be considered to have active and reactive members. The active member is the part involved in tooth movement; the reactive member serves as anchorage and involves the teeth that will not be displaced. A member sometimes can play an active and a reactive role simultaneously. For example, this clearly is the case when reciprocal anchorage is used.

On the subclinical level the three primary objectives are to control the center of rotation of the tooth, produce desirable stress levels in the PDL, and maintain a relatively constant level of stress. At the clinical level of observation the focus becomes the forces and moments produced by an orthodontic appliance. Specifically of interest are three important characteristics involving active and reactive members: (1) the M/F ratio, (2) the load-deflection rate, and (3) the maximal force or moment of any component of the appliance.

Moment-to-Force Ratio. To produce different types of tooth movement, the ratio between the applied moment and the force on the crown must be changed. As the M/F ratio is altered, the center of rotation changes. Crown tipping, translation, and root movement are examples of different types of tooth movement that can be produced with the proper M/F ratio. The important thing for the orthodontist to remember is that in few cases can desirable tooth movement be produced by applying a single force to the crown. If a modern orthodontic appliance is under consideration, an active member must be capable of producing the desired moment and force.

The M/F ratio is equally significant in the reactive member of the appliance. For example, if the practitioner is considering preserving anchorage of the posterior segments in an extraction case, to introduce a moment that tends to move roots forward and crowns back is desirable so that, combined with the mesial forces acting on the posterior segment, a more uniform distribution of stress is achieved in the PDL. A more uniform distribution of stress in the posterior segment minimizes forward displacement. The tip-back bend is one example in which a moment of this type is added to the posterior segment to enhance anchorage. In short, the M/F ratio determines the control the orthodontic appliance has over the active and reactive units; specifically, it controls the center of rotation of the tooth or a group of teeth.

Load-Deflection Rate. The second characteristic of an orthodontic appliance, the load-deflection (or torque-twist) rate, is a factor in the delivery of a relatively constant force.[38] By definition the load-deflection rate gives the force produced per unit activation. As the load-deflection rate declines for a tooth that is moving under a continuous force, the change in force value is reduced. For active members a low load-deflection rate is desirable for two important reasons: (1) a mechanism with a low load-deflection rate maintains a more desirable stress level in the PDL because the force on a tooth does not radically change magnitude every time the tooth has been displaced; and (2) a member with a low load-deflection rate offers greater accuracy in controlling force magnitude. For example, if a high load-deflection spring is used (e.g., an edgewise vertical loop), the load-deflection rate might be 1000 *g*/mm; this means that an error in adjustment of 1 mm could produce an error in force value of about 1000 *g*. However, if a low load-deflection spring is used, such as one with a rate of 10 *g*/mm, an error of 1 mm in activation affects the force value by only 10 *g*. Flexible members with low load-deflection rates require long ranges of activation to build up to optimal force values; hence they give the orthodontist greater control over the magnitude of force used.

If a low load-deflection rate is desirable for the active member of the appliance, the opposite is true for the reactive member. The reactive member should be relatively rigid; that is, it should have a high load-deflection rate. The anchorage potential of a group of teeth can be enhanced if the teeth displace as a unit. If individual teeth in the reactive unit tend to rotate around separate centers of rotation, higher stress distributions are produced in the PDL and the teeth can be more easily displaced. Another factor to consider is that the equal and opposite forces produced by the active members usually are distributed to localized areas, with just one or a few teeth involved. Localized tooth changes in these areas can be minimized if the reactive members of the appliance are sufficiently rigid. In short, the load-deflection rate is an indicator of the force required per unit deflection. In the reactive part of the appliance, a high load-deflection rate is needed when the orthodontist is dealing with a relatively rigid member.

Maximal Elastic Moment. The last characteristic of an orthodontic appliance that must be evaluated is the maximal elastic load or moment, which is the greatest force or moment that can be applied to a member without causing permanent deformation. Active and reactive members must be designed so they do not deform if activations are made that allow optimal force levels to be reached. In designing an appliance, a good idea is to go beyond required force needs and create a safety factor. Thus permanent deformation or breakage will not occur from accidental overloading, which can be caused by abnormal activation of an appliance or by abnormal forces during mastication.

All three of the important characteristics of an orthodontic appliance—the M/F ratio, the load-deflection rate, and the maximal elastic load or moment—are found within the elastic range of an orthodontic wire and therefore may be called spring characteristics. Beyond this range are the plastic changes that can occur in a wire up to the point of fracture. Although plastic changes are important in the design of an orthodontic appliance, they are not considered in detail in this discussion.

The designer controls a number of variables that influence spring characteristics; these variables are discussed individually in the following sections. The orthodontist always should keep in mind the relationship between these variables and the three important characteristics previously examined.

Manner of Loading

If an active member is to deliver continuous force for tooth movement, it must be able to absorb and release energy. Energy absorption in a flexible member results from the elastic deformations that occur during application of a force or load. Elastic deformations are changes in form or configuration that are reversible when the load is removed.

To understand the different types of loading and their significance, one must visualize a structural axis centrally positioned along a round wire (Figure 11-15). A force acting along the structural axis of the wire may produce compression or tension, shortening or elongating the wire. Thus, in tension and compression, the axial load may increase or decrease the length of the structural axis. This change is produced by force acting along the structural axis, and therefore is called an axial load. If a moment operates around the structural axis (i.e., at right angles to the lines of the structural axis), torsion is produced (Figure 11-16, *A*). In torsion the wire rotates around the structural axis, with the greatest elastic deformation occurring at the periphery of the wire. Bending, or flexure, is produced when the structural axis changes its configuration transversely or at right angles to its original structural axis. Bending can be produced by moments acting at right angles to the cross section of the wire (Figure 11-16, *B*) or by a transverse force acting on the wire (Figure 11-16, *C*).

The typical orthodontic appliance usually is not loaded in a simple manner. Tension, compression, torsion, and bending commonly are combined into a more complicated type of loading pattern referred to as

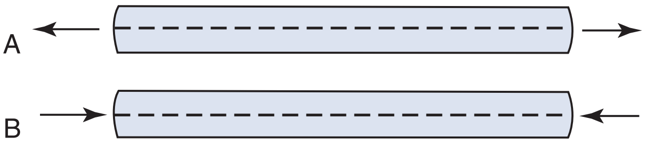

FIGURE 11-15 Axial loading. **A,** Tension. **B,** Compression. The force acts along the structural axis (*dotted line*).

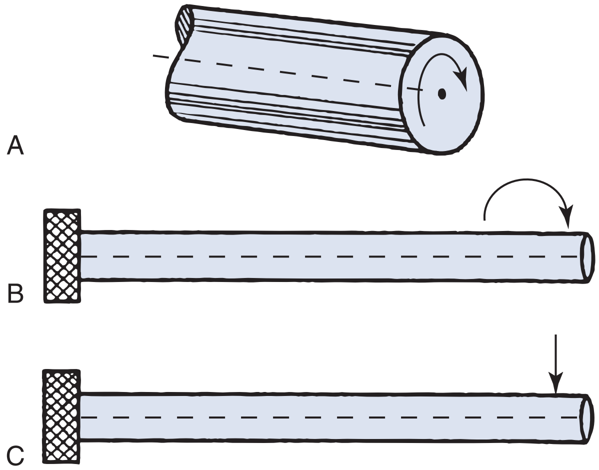

FIGURE 11-16 Torsion and bending. **A,** Torsion is produced by a couple acting around the structural axis. **B,** Pure bending is produced by the application of a couple. **C,** Bending is produced by a transverse force.

compound loading. Figure 11-17, *A*, shows two vertical loops in a round wire that can be used clinically to move a tooth buccally or lingually by displacing the central section at right angles to the surface of the paper. In reality, a compound deformation takes place, with bending occurring at point B and torsion or twisting at point A. During activation of this particular member, bending or torsion occurs. Figure 11-17, *B,* shows a vertical loop that can be used as a retraction spring. In a loop of this type, if the horizontal arms are kept parallel during activation, the loading pattern is fairly complicated. Not only are horizontal forces required, but two equal and opposite couples must be used to keep the horizontal arms parallel. Even though the loading pattern is more complicated in this example, the vertical loop undergoes only bending.

Certain types of loads, whether forces or moments, can produce certain changes in the structural axis of a wire, changes referred to as compression, tension, torsion, and flexure. A more sophisticated system of categorizing changes in a wire is to describe such changes in terms of the stress distribution throughout the length of the wire. This approach is not included in this discussion because a knowledge of stress-strain phenomena is required of the reader. One should remember, however, that resisting forces act throughout the wire during loading, resulting in certain internal factors of stress and strain. Reference is made to stress and strain only when absolutely necessary to develop a point.

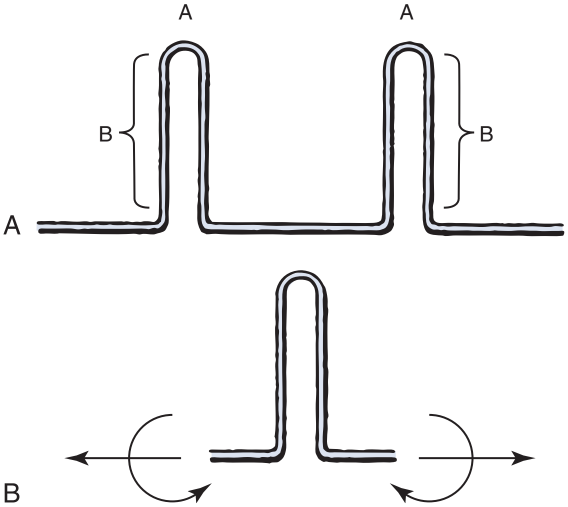

FIGURE 11-17 **A,** Displacement of the central portion of a loop at right angles to the page requires a force and a moment. Bending occurs at B and torsion at A. **B,** Opening a vertical loop requires a force and a moment to keep the horizontal arms parallel.

Axial loads that produce compression or tension are not useful for spring design because the load-deflection rate is high. An axial pull on a wire often is observed not to produce much elastic deformation, even with a heavy force, because the force is distributed uniformly as stress over each cross section of the wire. However, when nonuniform stress is distributed over various cross sections of wire (as in torsion and bending), the load-deflection rate may be low. For this reason, loading that leads to torsion and flexure is useful in the design of active or flexible members of an appliance.

If the maximal load or maximal torque were maintained as a constant, the load-deflection rate would be lowest in two particular types of loading: torsion and bending produced by moments alone. Such a low load-deflection rate might exist for a given maximal load because each cross section of the wire, from one end to the other, undergoes the same amount of torsion or bending. Loading of this type is ideal for spring design, but unfortunately in most instances more than a moment must be delivered to a tooth. Transverse loads therefore must be introduced, and these do not produce uniform changes along a wire unless the diameter of the wire differs along its length (i.e., a tapering wire).

In designing an orthodontic appliance, when should the orthodontist take advantage of tension, compression, torsion, and bending? A number of factors determine the manner of loading that should be used on a given member. For example, one configuration may be superior to another based on simplicity of design, general space available, or comfort in the mouth. Also, the M/F ratio needed to control the teeth partly determines the configuration to be used. For example, if equal and opposite moments are required, pure torsion or bending in a wire may be used. However, if moments and forces are required, primarily bending properties most likely will be used. In considering a reactive member, the forces should be distributed as axial loads whenever possible. For example, a transpalatal lingual arch can preserve widths of the posterior segments better than can a horseshoe lingual arch because the horseshoe-type arch bends more easily in this plane of space. Therefore one of the early steps in the design of an orthodontic member is to decide on its basic configuration, keeping in mind the objectives listed.

Of the variables that influence the spring characteristics of load-deflection rate (torque-twist rate), maximal elastic load or maximal elastic torque, and M/F ratio, only bending is considered in the following sections. Because most orthodontic configurations take advantage of bending as a major type of elastic deformation, many of the concepts (if not the exact formulations) also apply to torsion and axial loading.

Mechanical Properties of Metals

The mechanical properties of an alloy to be used in an orthodontic wire can be described on at least three levels. The most superficial is the observational level, on which the clinician operates. On this level, forces and deflection can be noted and measured. In other words, a certain amount of force in grams can be applied, and the wire will deflect by a certain number of millimeters. On the observational level the orthodontist is limited in how much can be understood and predicted about the nature of appliances.

The second level of description is the stress-strain level. On this level the orthodontist is dealing with pounds per square inch and deflection per unit length. These values cannot be measured directly, but they can be calculated from measurements made on the observational level. Most of the engineering formulations that can be used to predict changes in bodies subject to loads are based on stress-strain phenomena.

The third level of description is the atomic and molecular level. An understanding of events at the atomic and molecular level enhances the ability to predict responses and design new structures.

Basic Behavior of Alloys. Figure 11-18 is a theoretic diagram that plots load against deflection. It might represent, for instance, the load-deflection characteristics of an open coil spring. Deflection can be seen that from O to P_{max} (maximal elastic load) on the graph, a linear relationship exists between load and deflection. As the force increases, the deflection increases proportionately; this proportionality is referred to as Hooke's law. Load divided by deflection is a constant through this range and already has been defined as the load-deflection rate. At P_{max} a point is reached where load and deflection are no longer proportionate. Near P_{max}, permanent deformation is being produced in the spring, which will not return to its original shape. P_{max} represents the highest load that can be placed on the spring without permanent deformation; that is, the maximal elastic load. All the behavior found to the left of P_{max} on the graph lies in the elastic range, and behavior to the right lies in the plastic range. Elastic behavior is the ability of a configuration to return to its original shape after unloading; plastic behavior is the occurrence of permanent deformation in a configuration during loading. Finally, at the extreme right of the graph, the ultimate load (P_{ult}) is reached, at which point the spring will break. The diagram is a schematic one, and loads and deflections may not be so regular in commonly used orthodontic springs.

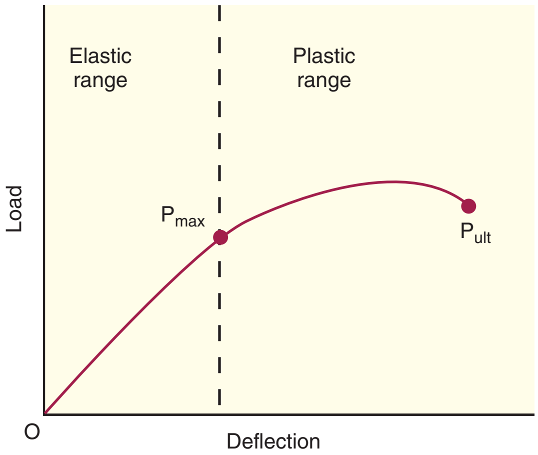

FIGURE 11-18 Load deflection. Note the linear relationship between load and deflection in the elastic range. P_{max}, Maximal elastic load; P_{ult}, maximal load before fracture.

Load-deflection diagrams of the type shown have a limited application because a separate diagram is required for every orthodontic member. However, if the stress-strain level is studied, one can make generalizations about orthodontic alloys that apply to any given alloy regardless of the configuration. The graph shown in Figure 11-19 plots stress against strain.* A diagram of this type corrects for the dimensions of the wire. The graph is identical in form to that of the load-deflection rate, except that the units are different. From O to EL (the elastic limit) is a straight line, denoting a linear relationship between stress and strain. This relationship is comparable to the relationship seen on the observational level between load and deflection. The ratio of stress to strain is referred to as the modulus of elasticity (E). As might be expected, this mechanical property determines the load-deflection rate of a spring.[39] The EL is the greatest stress that can be applied to the alloy without permanent deformation. The EL is analogous to the maximal elastic load and therefore is the mechanical

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*Stress in a wire is force per unit area applied to a cross section. Strain is deflection per unit length of the wire.

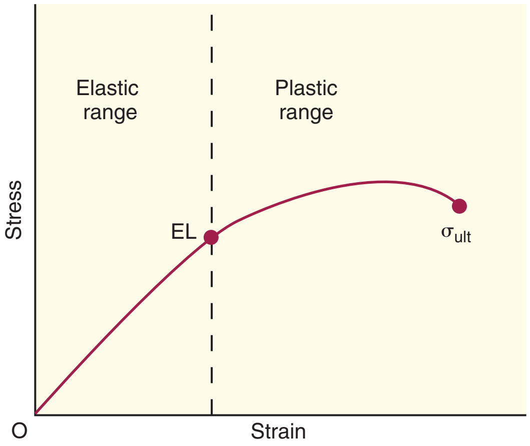

FIGURE 11-19 Stress-strain relationship. Note the linear relationship between load and deflection in the elastic range. *EL,* Elastic limit; σ_{ult}, tensile strength.

property that determines the ability of a member to withstand permanent deformation. A number of other terms describe this general part of the curve, such as yield point, yield strength, and proportional limit; these points are close to the EL, although they differ by definition. Finally, at the ultimate stress (tensile strength), the wire will fracture. As with loads and deflections, most actual alloys do not present such a regular and definitive pattern.

An explanation of elastic and plastic behavior would not be complete without a brief mention of atomic and molecular events. Fundamentally, elastic behavior involves interatomic bonding. Because atoms are pulled apart, a fairly definite relationship exists between stress and strain. However, plastic behavior involves displacement along slip planes, which are molecular, not atomic. Plastic behavior therefore is not as linear as elastic behavior.

Elastic Limit. The EL determines the maximal elastic load of a configuration. With respect only to the mechanical properties of the wire, the maximal elastic load varies directly and linearly with the EL. Manufacturers' data usually include the yield point or the tensile strength. The yield point is close to the elastic limit, but the tensile strength is higher.

In a given alloy (e.g., 18-8 stainless steel), a number of factors determine the elastic limit. The amount of work hardening produced during cold drawing of the wire sharply influences the EL.† Wires that have been considerably cold worked have a hard temper and therefore a high EL.[40] Small, round wires may have particularly high ELs because the percentage of reduction by cold working is high. Also, the cold worked outer core becomes proportionately greater in a wire of smaller cross section. Too much work hardening, however, produces a structurally undesirable wire that becomes highly brittle and may fracture during normal use in the mouth. Far better is to have a slightly lower EL so that an orthodontic member can deform permanently rather than break under accidental loading. Because the work hardening required to reduce the diameter of a wire increases the EL, anodic reduction is a poor method for reducing the size of the wire. Anodic reduction does not cold work a metal; therefore, the wire produced by that method has a lower EL than a work-hardened one, a circumstance that could lead to permanent deformation.

Many orthodontic alloys, such as Elgiloy and gold, can be heat treated to raise the EL, but the most commonly used alloy, 18-8 stainless steel, cannot. However, a stress relief process at 8508°F for 3 minutes or longer raises the apparent elastic limit of 18-8 stainless steel. Stress relief removes undesirable residual stress introduced during manufacturing and during fabrication by the orthodontist. If a single stress release is used, the optimal time to perform it is after all required bends and twists have been placed in the wire.

Modulus of Elasticity. The mechanical property that determines the load-deflection rate of an orthodontic member is the modulus of elasticity (E). Load-deflection varies directly and linearly with E (in torsion, linearly and directly as the modulus of rigidity). Steel has an E approximately 1.8 times greater than that of gold. A reactive member made of stainless steel is 1.8 times as resistant to deflection as one made of gold. With edgewise brackets and a 0.022-inch × 0.028-inch arch wire, for example, a steel wire gives greater control over the anchorage unit. However, activations made in a steel wire for tooth movement, if identical to the ones made in a gold wire of similar configuration, produce a load-deflection rate almost twice as high. For this reason steel and gold are not directly interchangeable in the design of an orthodontic appliance.[39,42]

Steel alloys are the alloys most commonly used for orthodontic wires. The E of most steel alloys is almost identical. Unlike the EL, the E is constant for a given alloy and is not influenced by work hardening or heat treatment.* Therefore, hard-temper wires do not have higher load-deflection rates than soft-temper wires. When changing the E of a piece of stainless steel, a new alloy must be chosen because nothing can be done to a steel alloy that will alter its E greatly.

Shape Memory Alloys. Within recent years two new alloys have been introduced in orthodontics: nickel titanium and beta-titanium (TMA).

Nickel titanium (nitinol) was developed by William F. Buehler in the early 1960s. The original alloy contained 55% nickel and 45% titanium, which resulted in a 1:1 stoichiometric ratio of these elements. The unique feature of this bimetallic (NiTi) compound is its memory, which is a result of temperature-induced crystallographic transformations. Andreasen and Hilleman[43] and Andreasen and Morrow[44] suggested that the orthodontist use these shape changes to apply forces. The shape memory principle is not used clinically. Instead, nitinol is used for its low force and high springback. The low E of nitinol, only 0.26 that of stainless steel, means that a 0.018-inch wire has the approximate stiffness of a 0.013-inch stainless steel wire. The most dramatic characteristic of nitinol, however, is its resistance to permanent deformation. NiTi wires can be activated over twice the distance of stainless steel, with minimal permanent deformation. Because permanent deformation is time dependent, though, additional small deformation occurs between adjustments. After bends or twists are placed, if the wire is activated in a direction opposite that used in forming the configuration, it easily deforms permanently.[45] Nitinol therefore is most useful when low forces and large deflections are needed in relatively straight wires. Nitinol is more brittle than stainless steel and cannot be joined by soldering or welding.[43]

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†Residual stress or other mechanisms can give an E that is slightly lower after work hardening.[17,41]

A new generation of shape memory alloys has been introduced into orthodontics and is referred to as superelastic.[46–50] Unlike nitinol, these alloys have a much lower transition temperature—either slightly below or slightly higher than mouth temperature. Generally speaking, the austenitic form of these alloys has a slightly higher springback than nitinol and may be less brittle. Figure 11-20 shows a loading and unloading curve for a superelastic NiTi wire at various activations. At the larger activations, part of the unloading curve is relatively flat. The clinical significance of this finding is that more constant forces are delivered to the teeth during the deactivation. Another interesting finding is that the stiffness is greater for small activations than for large activations. The typical orthodontic wire, however, is different because it has a relatively constant load-deflection rate, and it delivers increasing force, depending on the amount of activation.

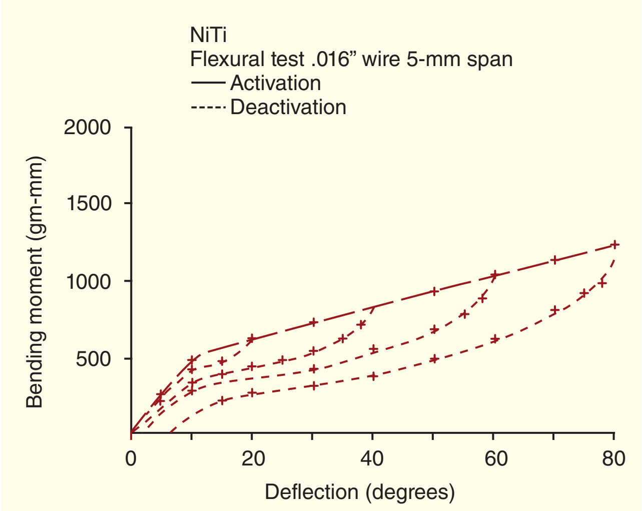

FIGURE 11-20 Activation and deactivation curves for NiTi wire. Unlike with stainless steel and Nitinol wires, the unloading curves for NiTi wire change at different activations. *(Redrawn from Tanne K, Sakuda M, Burstone CJ:* Am J Orthod Dentofac Orthop *92:499, 1987.)*

The superelastic NiTi wires are available in different degrees of stiffness. A true comparison of stiffness should be made at mouth temperature because some wires may appear to have lower forces because they are partly martensitic at room temperature.[51] Forces increase as a phase transformation occurs with mouth temperature. Although the final transition temperature of some superelastic NiTi wires is below mouth temperature, others are not activated fully until they reach 37°C or higher. These wires have both superelastic and shape memory properties. Generally, the heat treatment process performed during manufacture to raise the transition temperature allows for wires that deliver lower forces at mouth temperature; hence the orthodontist may be able to achieve full bracket engagement with larger wires earlier in treatment.

The superelastic NiTi wires and nitinol are limited in that they are not formed easily; also, through permanent deformation, they lose bends that are placed unless a heat treatment process is carried out. NiTi wires are brittle, and they usually are used in procedures that call for relatively straight wires and large deflections without permanent deformation.

TMA has a modulus of elasticity between that of steel and nitinol (approximately 0.4 times that of stainless steel).[52,53] TMA can be deflected up to 2 times as much as steel without permanent deformation. Unlike Nitinol, TMA is not significantly altered by the placement of bends and twists and has good ductility, equivalent to or slightly better than that of stainless steel, and can be welded without significant reduction in yield strength. Finger springs and hooks can be welded directly without solder reinforcement[54,55] (Figure 11-21).

Another new alloy introduced into orthodontics is titanium niobium. The alloy has low springback (equivalent to stainless steel) and is much less stiff than TMA. The alloy is useful when a highly formable wire with low forces in small activations is required.

Ideal Orthodontic Alloys. The ideal orthodontic wire for an active member is one that gives a high maximal elastic load and a low load-deflection rate. The mechanical properties that determine these characteristics are the EL and E. The ratio between the EL and E determines the desirability of the alloy: the higher the ratio, the better the spring properties of the wire. In the commercial development of new wires, the orthodontist should look for alloys that have a high EL and a low E. Small differences in the EL or E do not appreciably alter the ratio. For an alloy to be considerably superior in spring properties, it must possess a significantly higher ratio.

In the reactive member of an appliance, however, not only is a sufficiently high EL required, but also a high E is desirable. Because common practice is to use the same size slot or tube opening throughout a hookup, different

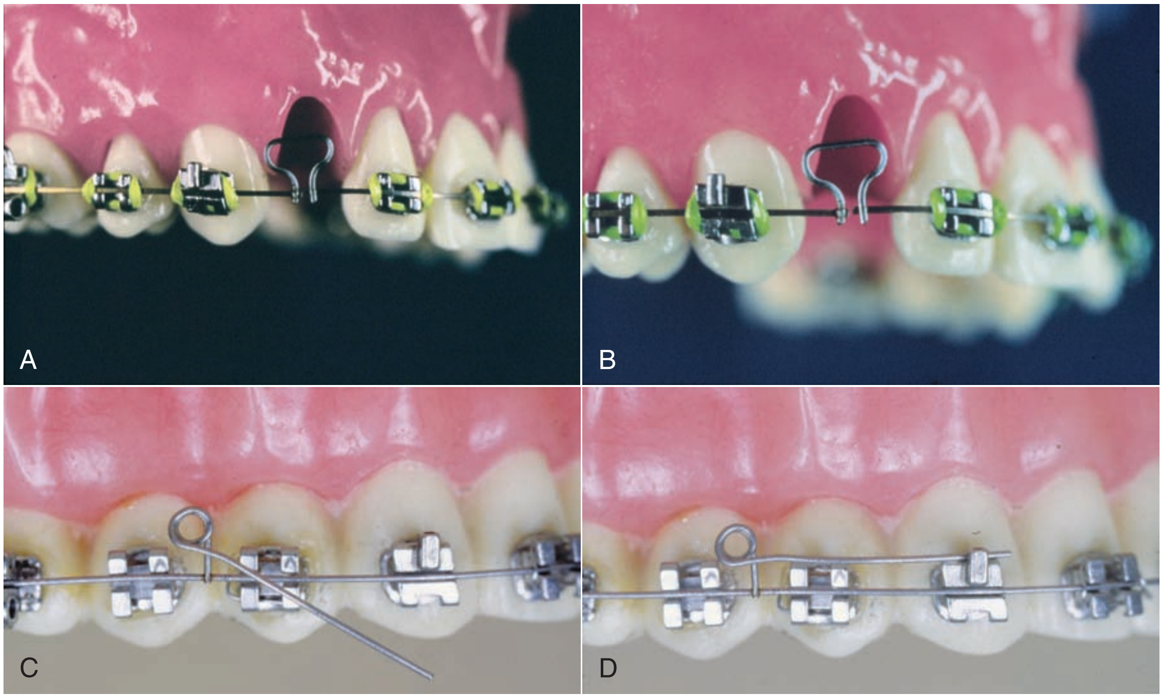

FIGURE 11-21 **A,** A vertical loop is welded to a continuous arch. **B,** The arch is cut between the loop forming a vertical loop arch. **C, D,** Welded helical spring used to erupt a high cuspid. The cuspid is now erupted and engaged in the arch wire. TMA wires can be welded directly together without significantly affecting the mechanical properties.

alloys can be combined in the same appliance to serve the needs of active and reactive members.

Four other properties of wire should be considered when evaluating an orthodontic wire: (1) the alloy should be reasonably resistant to corrosion caused by the fluids of the mouth; (2) the wire should be sufficiently ductile so that it does not fracture under accidental loading in the mouth or during fabrication of an appliance; (3) the wire should be able to be fabricated in a soft state and later heat treated to hard temper; and (4) the alloy should allow easy soldering of attachments.

A thorough knowledge of the mechanical and physical properties of an alloy is important in the design of an orthodontic appliance. However, these are but two of the many variables that determine the final form of an orthodontic mechanism.

Wire Cross Section

One of the crucial factors in the design of an orthodontic appliance is the cross section of the wire to be used. Small changes in cross section can influence the maximal elastic load and the load-deflection rate greatly.[38,56]

The maximal elastic load varies directly as the third power of the diameter of round wire, and the load-deflection rate varies directly as the fourth power of the diameter. The most obvious means of reducing the load-deflection rate of an active member may seem to be to reduce the size of the wire. However, the fallacy in reducing the size of the cross section is that the maximal elastic load also is reduced at an alarmingly high rate (as d^3). When designing active members, a good policy is to use as small a cross section as is consistent with a safety factor so that undue permanent deformation does not occur. Beyond this, any attempt to reduce the size of the cross section to improve spring properties may well lead to undesirable permanent deformation.

The fact that the load-deflection rate varies as the fourth power of the diameter in round wires suggests the crucial importance of selecting a proper cross section. For example, 0.018-inch wire is not interchangeable with 0.020-inch wire because with a similar activation (forgetting about play in the bracket), the 0.020-inch wire delivers almost twice as much force. The dramatic difference between wire sizes can be demonstrated further by comparing two similar activations in a 0.020-inch and a 0.010-inch round wire. The 0.020-inch wire delivers not twice as much force, but rather 16 times as much force, the load-deflection rate varying as the fourth power of the diameter.

In selecting a proper cross section for the rigid reactive members of an appliance, the load-deflection rate, rather than the maximal elastic load, is the prime consideration. Normal circumstances require a large enough wire cross section to give sufficient rigidity so that a sufficiently high load-deflection rate is ensured.

What is the optimal cross section for a flexible member? Generally, for multidirectional activations in which the structural axis is bent in more than one plane, a circular cross section is the structure of choice. Furthermore, because round wire is so widely available for commercial purposes, the mechanical properties of the wire and the cross-sectional tolerances are far superior to those of other cross sections. One of the drawbacks to round wire is that it must be properly oriented or activations may not operate in the intended plane. Moreover, round wire may rotate in the bracket and if certain loops are incorporated into the configuration, these can roll into the gingiva or the cheek. Many orthodontic wire configurations undergo unidirectional bending. For example, an edgewise vertical loop used for anterior retraction has a structural axis that bends in only one plane. For unidirectional bending, flat wire is the cross section of choice; more energy can be absorbed into a spring made of a flat wire than with any other cross section. This principle has been used for years in watch springs and other commercial designs. Hence flat (ribbon) wire can deliver lower load-deflection rates without permanent deformation more successfully than any other type of cross section. Another advantage of flat wire is that the problem of orientation is much easier to solve than with a round cross section. Flat wire can be anchored definitely into a tube or bracket so that it will not spin during deactivation of a given spring. Flat wire also can be used in certain situations when considerable tooth movement is required in one plane but limited tooth movement is needed in the other. For instance, if continuous ribbon wires are used (long-axis oriented occlusogingivally), positive leveling can be achieved occlusogingivally over a limited range, and buccolingual and labiolingual tooth alignment can be effected over a long range of action. A configuration of this type is useful when most of the problems are in the horizontal rather than the vertical plane.

For the reactive member, square or rectangular wire is superior to round wire because of the ease of orientation and greater multidirectional rigidity of the former, which leads to more definite control of the anchorage units. In the edgewise mechanism the assumption may be made that greater rigidity is needed buccolingually or labiolingually than occlusogingivally because an edgewise wire is used. This may or may not be true, depending on the intended use of the edgewise mechanism.

Selection of the Proper Wire (Alloy and Cross Section)

Selection of the proper size wire should be based primarily on the load-deflection rate required and secondarily on the magnitude of the forces and moments needed. Many orthodontists select a cross section of wire based on two other factors, which, although valid, are not as significant:

1. Some clinicians believe that increasingly heavier wires are needed in a replacement technique to eliminate the play between wire and bracket. In an edgewise appliance, however, the ligature wire minimizes much of the play in a first-order direction because it can fully seat within the brackets. Therefore, the clinician does not select a 0.018-inch over a 0.016-inch wire primarily because of the difference in play.
2. A wire also may be selected because it is believed that the smaller the wire, the greater the maximum elastic deflection possible; in other words, the smaller the wire, the more it can be deflected without permanent deformation. This is true, but maximal elastic deflection varies inversely with the diameter of the wire. A 0.016-inch wire has only 1.15 times as much maximal elastic deflection as a 0.018-inch wire; therefore the difference is negligible from a clinical standpoint. If the difference is 2:1 (as in 0.010-inch versus 0.020-inch wire), this factor becomes clinically significant.

The primary reason for selecting a particular wire size is the stiffness of the wire (i.e., its load-deflection rate). In a replacement technique, for example, the orthodontist might begin with a 0.014-inch wire that, deflected over 2 mm, gives the desired force. After the tooth had moved 1 mm, the wire can be replaced with a 0.018-inch wire, which gives almost the same force with 1 mm of activation.

Small differences in cross section produce big changes in load-deflection rates because in round wires the load-deflection rate varies as the fourth power of the diameter (Table 11-1). In bending, the stiffness, or load-deflection

TABLE 11-1 Factors Influencing Load-Deflection Rate, Maximal Load, and Maximal Deflection

Design Factor	Load-Deflection Rate	Maximal Load	Maximal Deflection
Addition of wire without changing length	Decreases	No change	Increases
Activation in direction of original bending		Increases	Increases
Material properties of wire	Increases as E	Increases as Sp	Increases as Sp/E
Wire cross section (d) (round)	d^4	d^3	1/d
Wire cross section (b, h) (rectangular)	bh^3	bh^2	1/h
Length (L) (cantilever)	$1/L^3$	1/L	L^2

d, Diameter, *h*, diameter in the direction of bending; *b*, direction at right angle to h, *E*, modulus of elasticity, *Sp*, proportional limit.

rate, is determined by the moment of inertia of the cross section of the wire with respect to the neutral axis. Clinicians are interested in the relative stiffness of the wire they use, but they have neither the time nor the inclination to use engineering formulas to determine these degrees of stiffness. Therefore, a simple numbering system has been developed, based on engineering theory, that gives the relative stiffness of wires of different cross sections if the material composition of the wire is the same.[56] The cross-sectional stiffness number (C_s) uses 0.1-mm (0.004-inch) round wire as a base of 1.

A 0.006-inch wire has a C_s of 5.0, which means that for the same activation, 5 times as much force is delivered. Tables 11-2 and 11-3 list, under the C_s column, stiffness numbers based on nominal cross sections. Manufacturing variation or mislabeling of wires obviously can change the actual C_s significantly. Two C_s numbers are given for rectangular wires—one for the first-order direction and one for the second-order direction.

The C_s of wire with a cross section of 0.016 inch is 256; this means that for an identical activation, it delivers 256 times as much force as a 0.004-inch round wire.

TABLE 11-2 Cross-sectional Stiffness Numbers (Cs) of Round Wires

Cross Section		
(in)	**(mm)**	**Cs**
0.004	0.102	1.00
0.010	0.254	39.06
0.014	0.356	150.06
0.016	0.406	256.00
0.018	0.457	410.06
0.020	0.508	625.00
0.022	0.559	915.06
0.030	0.762	3164.06
0.036	0.914	6561.00

From Burstone CJ: *Am J Orthod* 80:1, 1981. With permission from the American Association of Orthodontists.

The C_s of 0.018- × 0.025-inch wire in a first-order direction is 1865. Because the C_s for 0.016-inch wire is 256, a 0.018- × 0.025-inch wire in a first-order direction delivers 7.3 times as much force for the same activation. The assumption, for purposes of comparison, is that the wire configuration and the alloy are identical and only the cross section varies. Any two sections of wire can be compared for stiffness simply by dividing the C_s number of one into the other.

Figure 11-22 presents a graph of the C_s numbers for 0.014- to 0.018- × 0.025-inch wires. Although the full spectrum of available wire cross sections is not shown, it is apparent that load-deflection rates can vary by a factor of 10 or more if different-sized wires of a constant material (e.g., stainless steel) are used.

In the past, the cross section of wires has been varied to produce different degrees of stiffness. The overall stiffness of an appliance (S) is determined by two factors; one relates to the wire itself (W_s) and the other is the design of the appliance (A_s):

$$S = W_s \times A_s$$

where S is the appliance load-deflection rate; W_s, the wire stiffness; and A_s, the design stiffness factor. In general terms

$$\text{Appliance stiffness} = \text{wire stiffness} \times \text{design stiffness}$$

As the appliance design is changed by increasing wire between the brackets or by adding loops, the stiffness can be reduced as the design stiffness factor changes; however, the orthodontist is not concerned only with ways in which wire stiffness can be altered. Wire stiffness is determined by the cross section and the material of the wires:

$$W_s = M_s \times C_s$$

where W_s is the wire stiffness number, M_s, the material stiffness number; and C_s, the cross-sectional stiffness number. In general terms

$$\text{Wire stiffness} = \text{material stiffness} \times \text{cross-sectional stiffness}$$

TABLE 11-3 Factors Influencing Load-Deflection Rate, Maximal Load, and Maximal Deflection

	Cross Section		C_s	
Shape	**(in)**	**(mm)**	**First Order**	**Second Order**
Rectangular	0.010 × 0.020	0.254 × 0.508	530.52	132.63
Rectangular	0.016 × 0.022	0.406 × 0.559	1129.79	597.57
Rectangular	0.018 × 0.025	0.457 × 0.635	1865.10	966.87
Rectangular	0.021 × 0.025	0.533 × 0.635	2175.95	1535.35
Rectangular	0.0215 × 0.028	0.546 × 0.711	3129.83	1845.37

	Cross Section		
Shape	**(in)**	**(mm)**	**Cs**
Square	0.016 × 0.016	0.406 × 0.406	434.60
Square	0.018 × 0.018	0.457 × 0.457	696.14
Square	0.021 × 0.021	0.533 × 0.533	1289.69

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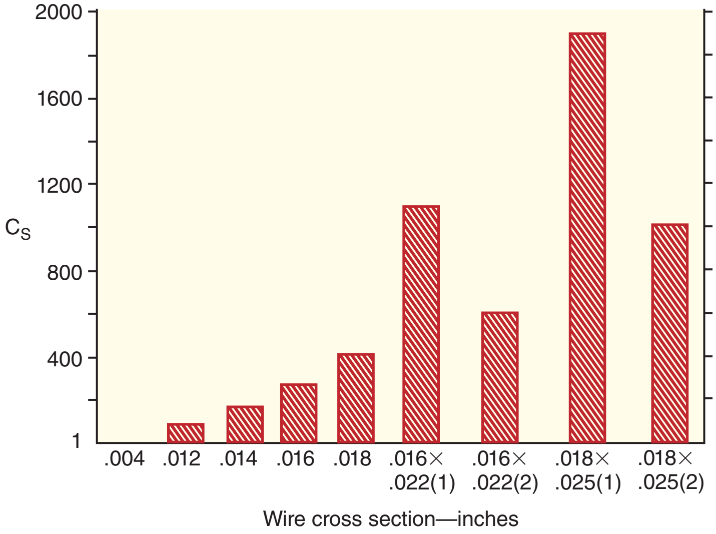


FIGURE 11-22 Cross section stiffness (C_s) numbers of orthodontic wires. Forces for any given activation are proportionate to the number. With varying cross sections, stiffness can vary by a factor of 10 or more.

Wire stiffness is determined by a cross-sectional property (e.g., moment of inertia) and a materials property (the E). In the past, because most orthodontists used only stainless steel with almost identical Es, only the size of the wire was varied and no concern was expended on the material property, which determines wire stiffness. With the availability of new materials, one can use the same cross section of wire but with different materials with differing degrees of stiffness to produce the wide range of forces and load-deflection rates required for comprehensive orthodontics.

Just as a simple numbering system proved useful for describing the relative stiffness of wires based on cross section, a similar numbering system can be used to compare relative stiffness based on the material. The material stiffness number (M_s) is based on the E of the material. Because steel currently is the most commonly used alloy in orthodontics, its M_s has been arbitrarily set at 1.0. Table 11-4 shows typical stiffness numbers for other alloys. Although the E is considered a constant, the history of the wire (particularly the drawing process) may have some influence on the modulus. Furthermore, differences in chemistry may make small changes in the recorded modulus. For practical clinical purposes, however, the M_s can be used to determine the relative amount of force a wire gives per unit activation. Note that TMA has an M_s of 0.42, which means that for the same appliance and wire cross section, a given activation delivers approximately 0.4 as much force as steel. Elgiloy wires deliver slightly more force than comparable wires of stainless steel, but for all practical purposes this increase is negligible.

TABLE 11-4 Material Stiffness Numbers (Ms) of Orthodontic Alloys and Braided Steel Wires*

Material	M_s
Alloys	
Stainless steel (ss)	1.00
TMA	0.42
Nitinol	0.26
Elgiloy blue	1.19
Elgiloy blue (heat treated)	1.22
Braids	
Twist-flex	0.18 to 0.20
Force-9	0.14 to 0.16
D-rect	0.04 to 0.08
Respond	0.07 to 0.08

From Burstone CJ: *Am J Orthod* 80:1, 1981. With permission from the American Association of Orthodontists. *Based on E = 25 × 106 psi.

In addition to new alloys, braided wires have been introduced into orthodontics. Braids take advantage of smaller cross sections, which have higher maximal elastic deflections, and in the process produce wires that have a relatively low stiffness. If the reader were to pretend that a braid was a solid wire and if nominal cross sections were used, it would be possible to establish an apparent E. Based on an apparent modulus, the material stiffness numbers are given for representative braided wires in Table 11-4. For instance, a 0.018-inch Respond wire braid has an M_s of 0.07 and delivers only 0.07 times the force of a 0.018-inch steel wire. The variation in M_s is depicted in a graph in Figure 11-23.

The load-deflection rate can be changed by keeping the wire size constant but varying the load-deflection rate significantly by altering the cross section. Maintaining a cross section of 0.018- × 0.025-inch wire, the wire stiffness (W_s) can be changed by using different materials.

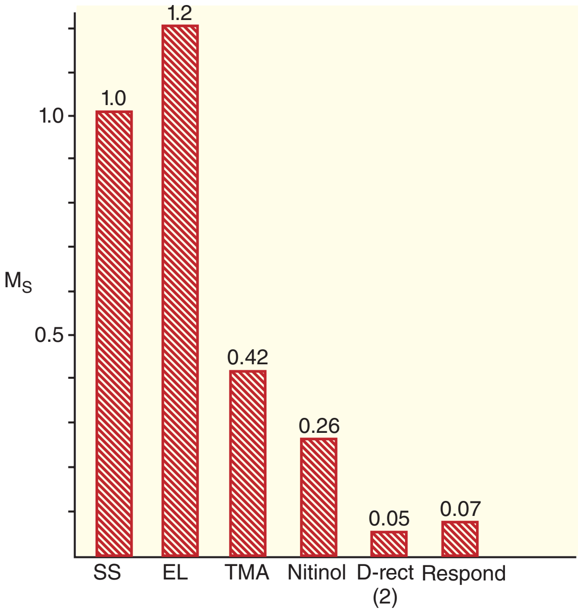


FIGURE 11-23 Material stiffness (M_s) numbers. Stainless steel has a base number of 1.0. The numbers for the other alloys and braids denote their stiffness in comparison with stainless steel. With variations in material, a range of stiffness is available equivalent to that for cross sections.

To obtain the Ws, the M_s must be multiplied by the C_s. For example, in a second-order direction for TMA,

$$W_s = M_s \times C_s \quad W_s = 0.42 \times 967 \quad W_s = 406.1$$

A 0.018- × 0.025-inch TMA wire has a W_s of 406.1, which is equivalent to a 0.018-inch round steel wire. Nitinol wire has a W_s of 251.4, which is similar to that of 0.016-inch steel wire. Braided wire (0.018 × 0.025 inch) with a W_s of 75.4 is similar to 0.012-inch steel wire. A full range of forces can be obtained by varying the material of the wire while keeping the cross section the same (Figure 11-24). The W_s numbers for 0.018-inch round wire of different materials are shown in Figure 11-25.

Using the principle of variable cross-sectional orthodontics, the amount of play between the attachments and the wire can be varied, depending on the stiffness required. With small, low-stiffness wires, excessive play may lead to lack of control over tooth movement. However, if the principle of variable-modulus orthodontics is used, the clinician determines the amount of play required before selecting the wire. In some instances more play is needed to allow the brackets freedom of movement along the arch wire. In other situations minimal play is allowed to ensure good orientation and effective third-order movement. After the desired amount of play has been established, the correct wire stiffness can be produced by using a material with a proper M_s. In this way the play between the wire and the attachment is not dictated by the stiffness required but rather is under the full control of the operator.

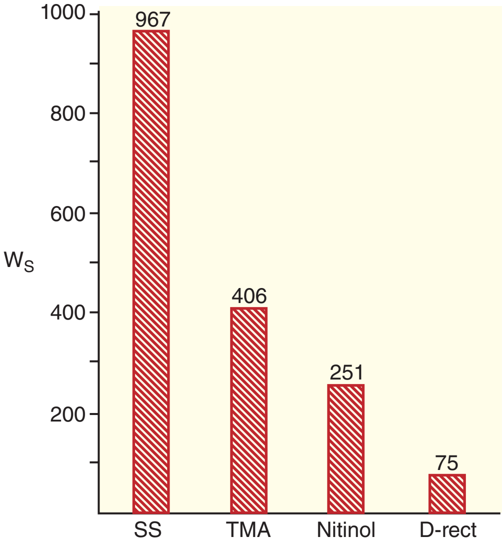


FIGURE 11-24 Wire stiffness (W_s) numbers of 0.018- × 0.025-inch wires in second-order direction. Forces for the same activations are proportionate to the W_s numbers. A full range of forces can be obtained by keeping a constant cross section (e.g., 0.018 × 0.025 inch) but using different materials.

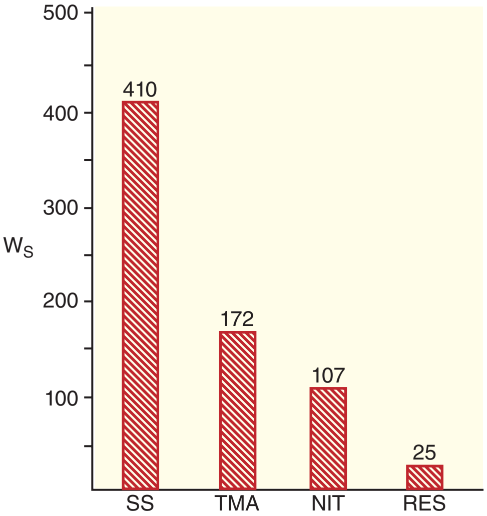


FIGURE 11-25 W_s numbers for 0.018-inch round wires. Figures 7-26 and 7-27 show wide stiffness ranges when the occlusogingival wire dimension is kept constant at 0.018 inch.

The variable-modulus principle allows the orthodontist to use oriented rectangular wires or square wires in light force and heavy force applications and stabilization. A rectangular wire orients in the bracket and thus offers greater control in delivering the desired force system; it is easier to bend because the orientation of the wire can be checked carefully. More important, when placed in the brackets, the wire does not turn or twist, allowing the forces to be dissipated in improper directions.

Wire Length

The length of a member may influence the maximal elastic load and the load-deflection in a number of ways, depending on the configuration and loading of the spring. The cantilever has been chosen to demonstrate the effect of length because the cantilever principle is widely used in orthodontic mechanisms. A finger spring may be visualized for the following discussion.

Figure 11-26 shows a cantilever attached at B with a vertical force applied at A. The distance L represents the length of the cantilever measured parallel to its structural axis. In this type of loading the load-deflection rate varies inversely as the third power of the length; in other words, the longer the cantilever, the lower is the load-deflection rate. The maximal elastic load varies inversely as the length of the cantilever. Again, the longer the cantilever, the lower is the maximal elastic load.

Increasing the length of the cantilever is a better way to reduce the load-deflection rate than is reducing the cross section. Increasing the length of the cantilever greatly reduces the load-deflection rate, yet the maximal elastic load is not changed radically because it varies linearly with the length. Adding length within the practical confines of the oral cavity is an excellent way to improve spring properties.

Another way of loading the cantilever is shown in Figure 11-27, this time by means of a couple or moment applied to the free end. With a couple applied at the free end, the moment-deflection rate varies inversely as the second power of the length. Interestingly, the maximal elastic moment is not affected at all by changes in length. The length may be doubled or tripled, but the maximal elastic moment remains the same. This is a most desirable type of loading because additional length can reduce the moment-deflection rate, but the maximal elastic moment is not reduced. However, the principle can be applied only if moments alone are required for a given tooth movement.

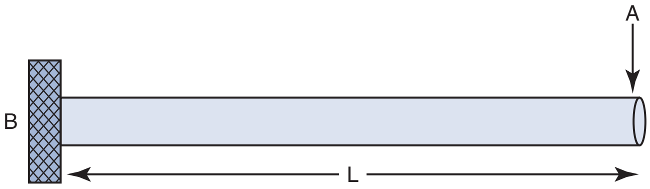


FIGURE 11-26 Cantilever *(B)* with load *(L)* applied at the free end *(A)*.

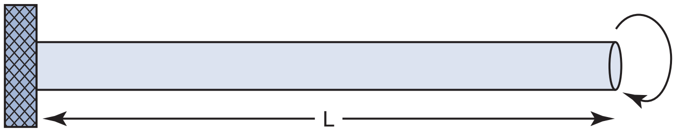


FIGURE 11-27 Cantilever with an applied couple; the effect is uniform bending along the wire.

Increasing the length of a wire with vertical loops is one of the more effective means of reducing load-deflection rates for flexible members and at the same time only minimally altering their maximal elastic loads. However, limitations exist on how much the length can be increased. The distance between brackets in a continuous arch is predetermined by tooth and bracket width. Vertical segments in the wire are limited by occlusion and the extension of the mucobuccal fold. An application that shows the way in which added length in a wire achieves more constant force delivery without radically sacrificing maximal elastic load is the use of a 0.018- × 0.025-inch TMA intrusion arch (Figure 11-28). The arch is used to depress maxillary anterior teeth in the correction of deep overbite.[57–59] The long distance from an auxiliary tube on the buccal stabilizing segment to the midline of the incisor is responsible for a more constantly delivered depressive force on the anterior teeth.[60,61]

Amount of Wire

Additional length of wire may be incorporated in the form of loops or helices or some other configuration. This tends to lower the load-deflection rate and increase the range of action of the flexible member. The maximal elastic load may or may not be affected.

When a member is to incorporate additional wire, the parts of the configuration where additional wire should be placed must be located properly, and the form the additional wire should take must be determined. If location and formation are done properly, lowering the load-deflection rate without changing the maximal elastic load should be possible merely by adding the least amount of wire that will achieve these ends.

Consider the problem of the cantilever in relation to the placement of the additional wire. In Figure 11-29 a cantilever is shown with the vertical force of 100 *g* at the free end. Imaginary vertical sections can be cut along the length of the wire, and at each of these sections a bending can be calculated. The bending moment is found by multiplying the load at the end of the cantilever by the perpendicular distance to the section in question; therefore the bending moment at the point of force application at the free end of the wire is zero. Approximately 1 mm closer to the point of support, it is 100 *g*-mm. At 2 mm closer, it is 200 *g*-mm. Finally, at the point of support, the bending moment is 1000 *g*-mm. The bending moment represents an internal moment resisting the 100-g force applied to the free end of the cantilever. The significance of the bending moment is that the amount of bending at each cross section of the wire is directly proportionate to the magnitude of the bending moment; in other words, the greater the bending moment at any particular cross section, the more the wire is going to bend at that point.

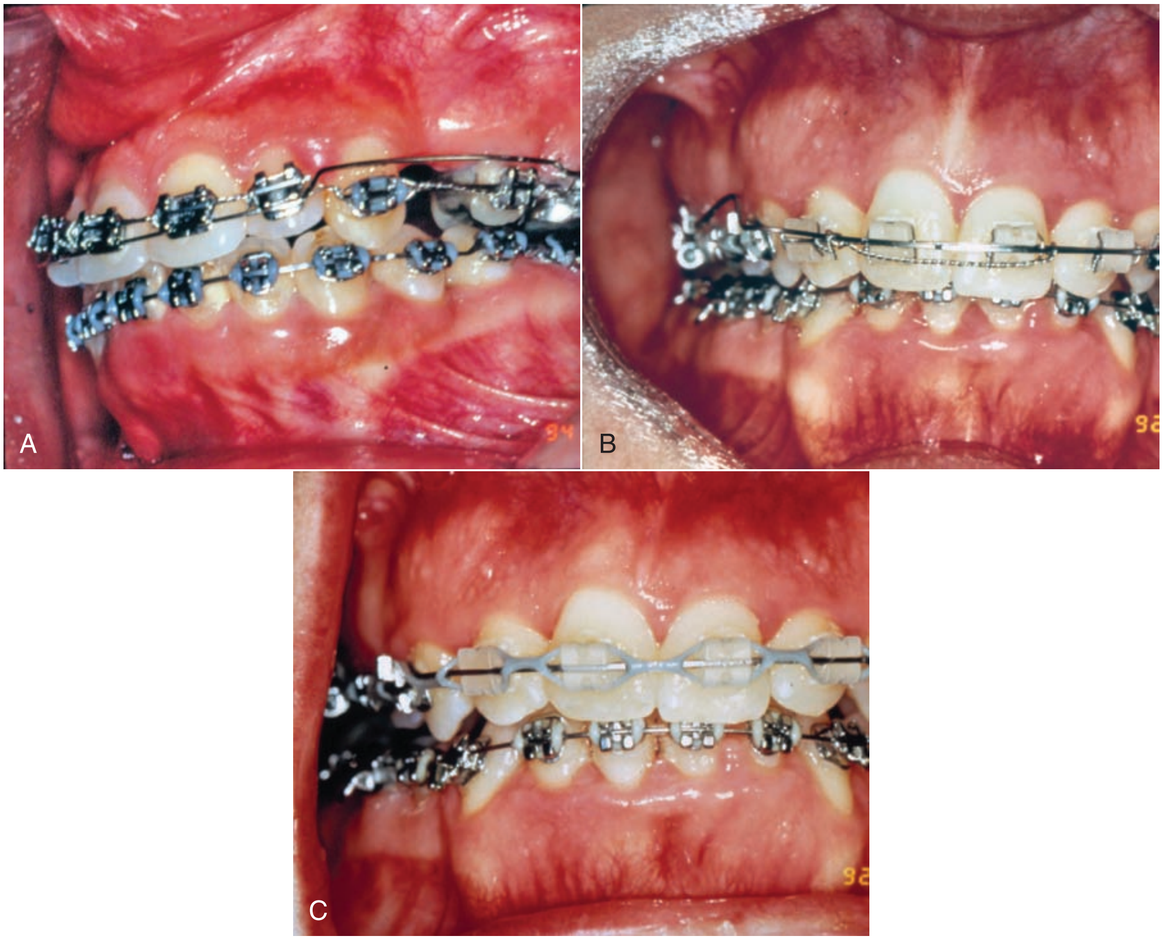


FIGURE 11-28 Intrusion arches deliver relatively constant force because of the sizable distance between the molar tube and incisor tie. **A,** An intrusion arch showing a canine bypass. **B,** A patient with deep overbite requiring intrusion; 11 mm (60 *g)* of activation. **C,** After intrusion.

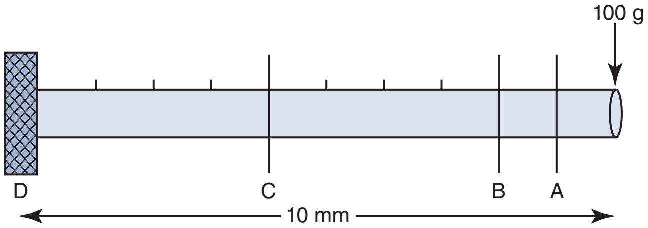


FIGURE 11-29 Cantilever with load applied at the free end. *A–C,* Imaginary perpendicular sections. *D,* Point of support.

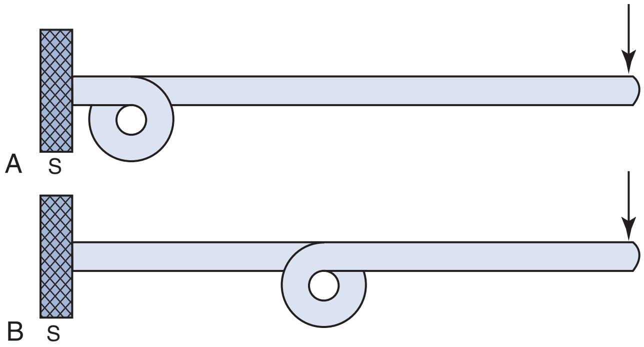


FIGURE 11-30 Placement of a helical coil in a cantilever. **A,** Correct. **B,** Incorrect. *S,* Point of support.

The optimal place for additional wire is at cross sections where the bending moment is greatest. In the case of the cantilever, the position for additional wire is at the point of support because the bending moment is greatest there: 1000 *g*-mm. Helical coils can be used to reduce the load-deflection rate. Figure 11-30 illustrates the proper positioning of a helical coil for this purpose. The load-deflection rate is maximally lowered for the amount of wire used if the helix is placed at the point of support.

Placement of additional coils at the point of support in a cantilever does not change the maximal elastic load. A straight wire of a given length and a wire with numerous coils at the point of support have identical maximal elastic loads, provided they have the same length measured from the force to the point of support. This should not be surprising because the maximal elastic load is a function of this length of the configuration rather than of the amount of wire incorporated

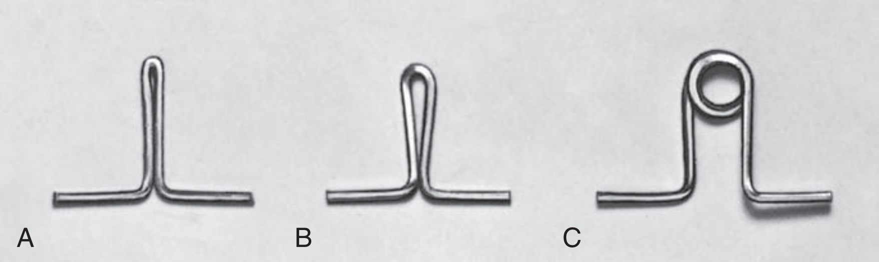


FIGURE 11-31 Vertical loops. **A,** Squashed loop. **B,** Plain loop. **C,** Loop with a helical coil.

into it. This is true of many other configurations as well: the load-deflection rate can be lowered without changing the maximal elastic load if additional wire is incorporated properly. This is important from a design standpoint because it provides a method of lowering the load-deflection rate without subsequently reducing the maximal elastic load.

As mentioned previously, to achieve this objective using the minimal amount of wire, the best placement of additional wire is at cross sections where the bending moment is greatest. A practical way of deciding where these parts of a wire might be is to activate a configuration and see where most of the bending or torsion occurs. The sections where the bending or torsional moments are greatest are the cross sections with the greatest stress. The configuration of the additional wire should be such that maximal advantage can be taken of the bending and torsional properties of the wire. In short, the amount of wire used is not what is important in achieving a desirably flexible member, but rather the placement of the additional wire and its form.

Although additional wire is helpful in the design of flexible members, it should not be used in reactive or rigid members. Loops and other types of configurations diminish the rigidity of the wire and thus may be responsible for some loss of control over the anchor units.

Stress Raisers

From a theoretic point of view, the force or stress required to deform a wire permanently can be calculated; however, in many cases the wire deforms at values much lower than the predicted one because local stress raisers increase the stress values in a wire far beyond what might be predictable by commonly used engineering formulas.

Two common stress raisers are sudden changes in cross section and sharp bends. Any nick in a wire tends to raise the stress at that cross section and hence may be responsible for permanent deformation or fracture at that point. For this reason, one should not use a file to mark a wire, particularly the small cross-sectional wires used in the flexible member of an appliance.

A sharp bend in a wire also may result in higher stress than that which might be predicted for a cross section of wire. A sudden sharp bend deforms far more easily than a more rounded or gradual bend. Unfortunately, with a continuous arch wire the orthodontist is limited in space between brackets and many times must make sharp bends because of this limitation. Flexible members should be designed with gradual bends so that they are less troubled by permanent deformation than comparable members with sharp or sudden bends.

For example, three vertical loops might be compared: a squashed one, a plain one, and one with a helical coil (Figure 11-31). In terms of permanent deformation the poorest design is loop A, which because of its squashed state has a sharp bend at its apex. The plain vertical loop (B) is slightly superior because the bending is more gradual; nevertheless, a fairly sharp bend occurs at its apex. The configuration with the most gradual bending is the loop with a helical coil (C). Not only does the helical coil enhance the flexible properties of the spring because of its additional wire, but also the lack of sharp bends further increases its range of action without permanent deformation. (Proper direction of activation is discussed later.)

Sections of Maximal Stress

Certain sections along a wire are points of maximal stress; these sections may be called critical sections. As discussed previously, sections in which the bending moments are greatest are areas of high stress. These critical sections are important from a design viewpoint because they are the locations where permanent deformation is most likely to occur.

A number of precautions should be observed at a critical section. First, stress raisers should be avoided in these sections at all costs. A nick in a wire, for instance, might not be so disastrous if the stress is low but might well lead to deformation or fracture where the stress level is high. Second, the EL of the wire should be watched carefully at a critical section. Operations such as soldering may overheat the wire, reducing its EL. Lowering the EL at another place in the wire where stress is low may not be too undesirable but could be responsible for failure at a critical section. Therefore in high-stress areas an auxiliary should be attached by some means other than soldering; if soldering is used, it should be done with considerable care.

An example of permanent deformation or fracture produced by a sudden change in cross section and a

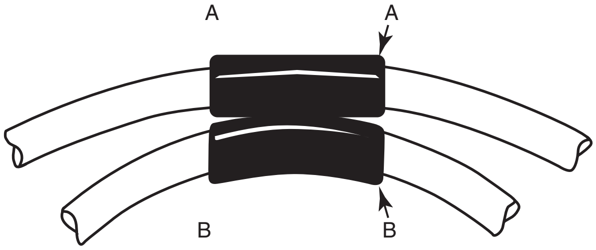


FIGURE 11-32 Face-bow: the anterior portion of the inner and the outer bow. *A,* The juncture of the solder and the outer bow is a stress point. *B,* Another stress point is found at the juncture of the solder and the inner bow.

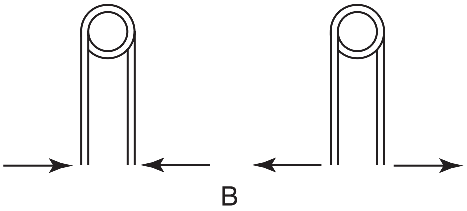


FIGURE 11-33 Activation of a loop with a helical coil. **A,** Correct. **B,** Incorrect.

lowering of the EL can be seen in the face-bow in Figure 11-32.[62,63] A stress point is found at the juncture of the solder and the outer bow (A) and secondarily at the juncture of the solder and the inner bow (B). At A, the wire may be structurally weak for two reasons: the stress point associated with the sudden change of cross section and a lowering of the EL because of the soldering operation. A also happens to be a critical section where stress is high; therefore, it is a predictable area of fracture in a face-bow of this design.

If the orthodontist is in doubt about which parts of an appliance have critical sections, the appliance can be activated in a typical manner and the parts that exhibit the most bending or torsion noted. These generally have high stress along their cross sections.

One must keep in mind three rules in the design of critical sections: (1) all stress raisers should be eliminated as much as possible; (2) a larger cross section can be used to strengthen this part of the appliance; and (3) the appliance may be so designed that it elastically rather than permanently deforms under normal loading. Many times a highly flexible member is more serviceable than a rigid one because the flexible member can deflect out of the way of the oncoming load. A light, flexible spring can withstand occlusal trauma far better than a more rigidly constructed one because it can displace elastically away from an occlusal force. Because the wings of airplanes are flexible, they are less apt to fracture under normal flying conditions. Similarly, increasing the flexibility of a member may be a way of preserving the integrity of the appliance.

Direction of Loading

Not only is the manner of loading important, but also the direction in which a member is loaded can influence its elastic properties greatly. If a straight piece of wire is bent so that permanent deformation occurs and an attempt is made to increase the magnitude of the bend, bending in the same direction as had originally been done, the wire is more resistant to permanent deformation than if an attempt had been made to bend in the opposite direction. The wire is more resistant to permanent deformation because a certain residual stress remains in it after placement of the first bend. A flexible member will not deform as easily if it is activated in the same direction as the original bends were made to form the configuration. If a bend is made in an orthodontic appliance, the maximal elastic load is not the same in all directions; it is greatest in the direction identical to the original direction of bending or twisting. The phenomenon responsible for this difference is known as the Bauschinger effect.

Figure 11-33 shows a vertical loop with a coil at the apex and a number of turns in the coil under different directions of loading. The type of loading in A tends to wind the coil, increasing the number of turns in the helix and shortening the length. The type of loading in B tends to unwind the helix, reducing the number of coils and lengthening the spring. The loading in Figure 11-33, *A*, tends to activate the spring in the same direction as it originally was wound and thus is the correct method of activation. In many configurations in which residual stress is high, such as a vertical loop that uses a number of coils at the apex, the range of action can vary 100% or more between correct and incorrect loading. Obviously this is a much more significant factor in design than are small differences in the mechanical properties of the wire.

The same principles can be applied to less complicated configurations, such as a continuous arch wire. The orthodontist should be sure that the last bend in an arch wire is made in the same direction as the bending produced during its activation. For example, if a reverse curve of Spee is to be placed in an arch wire, the curve first should be overbent and then partly removed; only then will activation of the arch wire occur in the same direction as the last bend (Figure 11-34). The same is true of a series of tip-back bends. The tip-back bend should be increased beyond the amount required, and then some of it should be removed. In this way, bending during activation of the tip-back bend when it is placed in the brackets occurs in the same direction as the last bend.

Attachment

If forces and moments are to be delivered to a tooth, some means of attachment is necessary. If forces alone were sufficient without the use of moments, the attachment could be relatively simple; however, this usually is

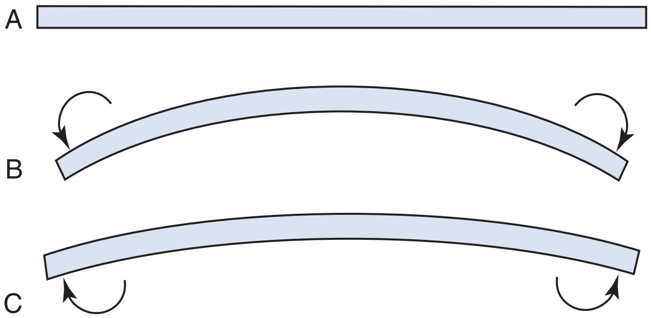


FIGURE 11-34 Placing a reverse curve of Spee in a lower arch.* **A,** Original straight wire. **B,** Wire overbent. **C,** Final configuration. Note that the last bends are in the same direction as the activation in the mouth. *References 4, 6, 66–70.

not the case. Most orthodontic movements require moments and forces. Moments and forces can be produced if a noncircular wire is oriented in a noncircular bracket. The edgewise bracket and tube are excellent examples of the use of a noncircular cross section for wire and attachment. However, loops can be used to obtain an orientation of round wire that allows moments and forces to be delivered.

What are the optimal dimensions for a bracket or tube? This question has no definitive answer unless the objectives and design of an orthodontic appliance are specified fully. However, some of the factors involved in making this decision can be discussed.[64]

The starting point in the design of a bracket is determining the width of the bracket (mesiodistal dimension). From a theoretic viewpoint a system of forces and moments can be produced regardless of the mesiodistal width of the brackets. However, width becomes important for two reasons. First, wider brackets minimize the amount of play between the arch wire and attachments. A certain amount of leeway must exist between the arch wire and the bracket, or easy bracket engagement becomes impossible. However, if a bracket is too narrow, considerable play may exist in all planes between wire and bracket. If the bracket is wider, the arch wire has a much more positive purchase. Second, the greater the distance between the brackets, the lower the load-deflection rate. Because at least part of the movement required to treat a patient is produced by adjustments between brackets, it is desirable that the distance between attachments be as great as possible. One of the problems of the continuous arch is the sharp limitation of space between brackets, no matter how narrow the brackets might be.

The decision on proper bracket width lies between two extremes. At one end a bracket might be as wide as the tooth. In this instance, however, the interbracket distance is not enough to produce sufficient flexibility for adjustment. At the other end a knife-edge bracket offers the greatest interbracket distance and thus the most desirable load-deflection rates. With a knife-edge bracket, however, delivering the necessary moments and forces to achieve full control over tooth movement is impossible.[65] Generally speaking, the ideal bracket width is one that is as narrow as possible yet still capable of obtaining positive purchase on an arch wire so that moments can be delivered to teeth.

Optimal occlusogingival slot dimensions are determined by the maximal elastic loads required from the active and reactive members. A safe rule is to design based on the reactive members, ensuring that the bracket and tube slots are large enough for rigid control of anchor units. Designing primarily based on the active members is a mistake that may lead to the use of slots that are too small to control the anchor teeth and withstand the forces of mastication.

A vexing problem in orthodontic treatment arises when appliance requirements change between stages of treatment. Teeth that at one time are being moved actively may later become reactive units. For convenience, in the typical strap-up the same dimensions are used in all slots throughout the arch; yet the active and reactive requirements are not the same throughout the arch. One objective in the design of an appliance is to ensure a positive fit between different cross sections of wire, depending on the needs of the case. An edgewise bracket can become adjustable in a buccolingual or labiolingual direction by means of a ligature tie, but it is not adjustable occlusogingivally. Thus no definite answer can be given to the question of optimal occlusogingival slot dimension. The decision depends on many factors, including the general concept of treatment and the basic design of an orthodontic appliance.

Forces from a Continuous Arch

A multibanded appliance, such as that used in edgewise mechanics, produces a complicated set of forces and moments. For example, a straight (ideal) arch placed between irregular brackets on malaligned teeth may deliver desirable and undesirable forces. An analysis of two-tooth segments (two teeth connected by a straight wire) can demonstrate some of the problems encountered when adjacent brackets are connected by a continuous wire or arch.[4,6,66–70]

The force system produced in a two-tooth segment is determined by the angle of the bracket (θ_A and θ_B) with respect to the straight wire and the interbracket distance (Figure 11-35). Based on the ratio θ_A/θ_B, six classes of force systems can be described (Figure 11-36). The force system for each class is given in Table 11-5. Note that the ratio of the moments at bracket A with respect to bracket B is constant for each class. Lines 2 and 3 of Table 11-5 give the force systems acting on the wire; line 5 reverses the direction, showing the forces acting on the teeth. What is apparent is that forces and moments and their ratios may not be correct to produce the desired changes in a malocclusion without side effects.[71,72]

For example, Figure 11-37, *A*, shows a Class I geometry in which the second premolar is supererupted in relation to the first molar. A straight wire placed on the premolar produces a desirable intrusive force; unfortunately, however, the moment produced on the premolar is undesirable, displacing the root mesially. This can be avoided by using a noncontinuous configuration, the rectangular loop. Figure 11-37, *B*, shows the force system from the rectangular loop, which can be designed to produce a intrusive single force and no moment on the premolar. Figure 11-38 shows a rectangular loop used to rotate and extrude a premolar. Rectangular loops and other loop designs offer the potential for delivering desired force systems with minimal side effects, which is not usually possible with the continuous arch.[57,58] Loops are not used only to lower forces; they change the entire force system.

Straight wires may reduce desirable or undesirable force systems. The undesirable components of the forces can produce unwanted tooth movement during the

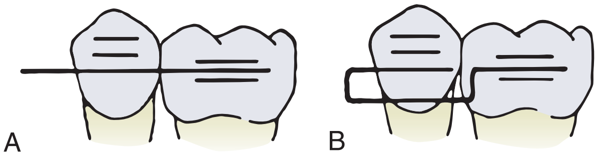


FIGURE 11-37 **A,** A straight wire (ideal arch) between the first molar and premolar produces an undesirable positive movement that displaces the premolar root mesially. **B,** A rectangular loop used for the same bracket malalignment produces no side effects on the premolar because only an intrusive force is delivered.

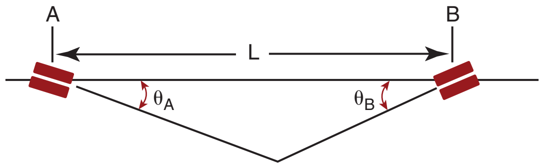
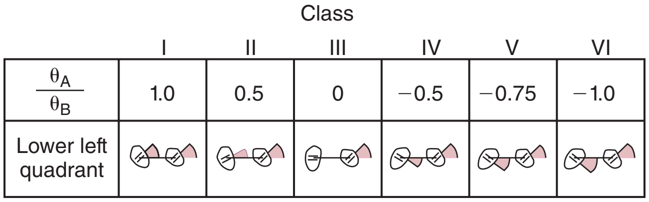


FIGURE 11-35 The geometry of the wire to an edgewise bracket is defined by the interbracket distance (L) from the angles of the brackets with respect to the interbracket axis. *(From Burstone CJ, Koenig HA: Am J Orthod 65:270, 1974. With permission from the American Association of Orthodontists.)*



	Class					
	I	II	III	IV	V	VI
$\frac{\theta_A}{\theta_B}$	1.0	0.5	0	−0.5	−0.75	−1.0
Lower left quadrant						

FIGURE 11-36 The six basic geometries based on the ratio q_A/q_B. Classes are independent of interbracket distance. Position *A* is the canine; position; *B,* the premolar.

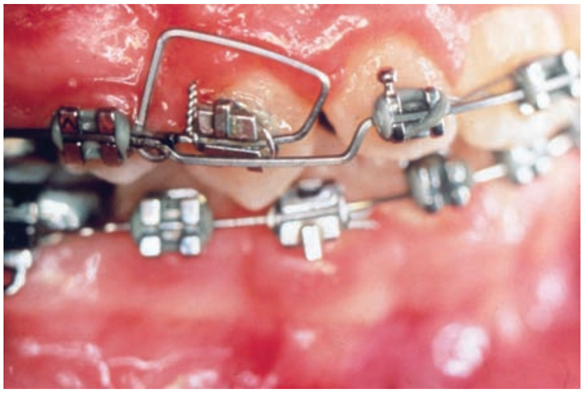


FIGURE 11-38 A rectangular loop is used to rotate and extrude the upper cuspid without a side effect. Note bypass arch for added anchorage.

TABLE 11-5 **Force Systems by Class**

Class	I	II	III	IV	V	VI
$\frac{\theta_A}{\theta_B}$	1.0	0.5	0	–0.5	–0.75	–1.0
$\frac{M_A}{M_B}$	1.0	0.8	0.5	0	–0.4	–1.0
Force system on wire at yield (L = 7 mm)	531.4↑ ↓531.4 1860↺ ↺1860	477.4↑ ↓477.4 1468↺ ↺1860	398.0↑ ↓ 398.0 930↺ ↺1860	265.7↑ ↓265.7 ↺1860	160.0↑ ↓160.0 740↻ ↺1860	1860↻ ↺1860
Force system on wire at yield (L = 21 mm)	177.0↑ ↓177.0 1860↺ ↺1860	160.0↑ ↓160.0 1468↺ ↺1860	133.0↑ ↓133.0 930↺ ↺1860	88.6↑ ↓88.6 ↺1860	53.3↑ ↓53.3 740↻ ↺1860	1860↻ ↺1860
Relative force system on teeth (L = 7 mm)	531.4↑ ↓531.4 1860↻ ↻1860	477.4↑ ↓477.4 1468↻ ↻1860	398.0↑ ↓ 398.0 930↻ ↻1860	265.7↑ ↓265.7 ↻1860	160.0↑ ↓160.0 740↺ ↻1860	1860↺ ↻1860

From Burstone CJ, Koenig HA: Force systems from an ideal arch, *Am J Orthod* 65:270, 1974. With permission from the American Association of Orthodontists.

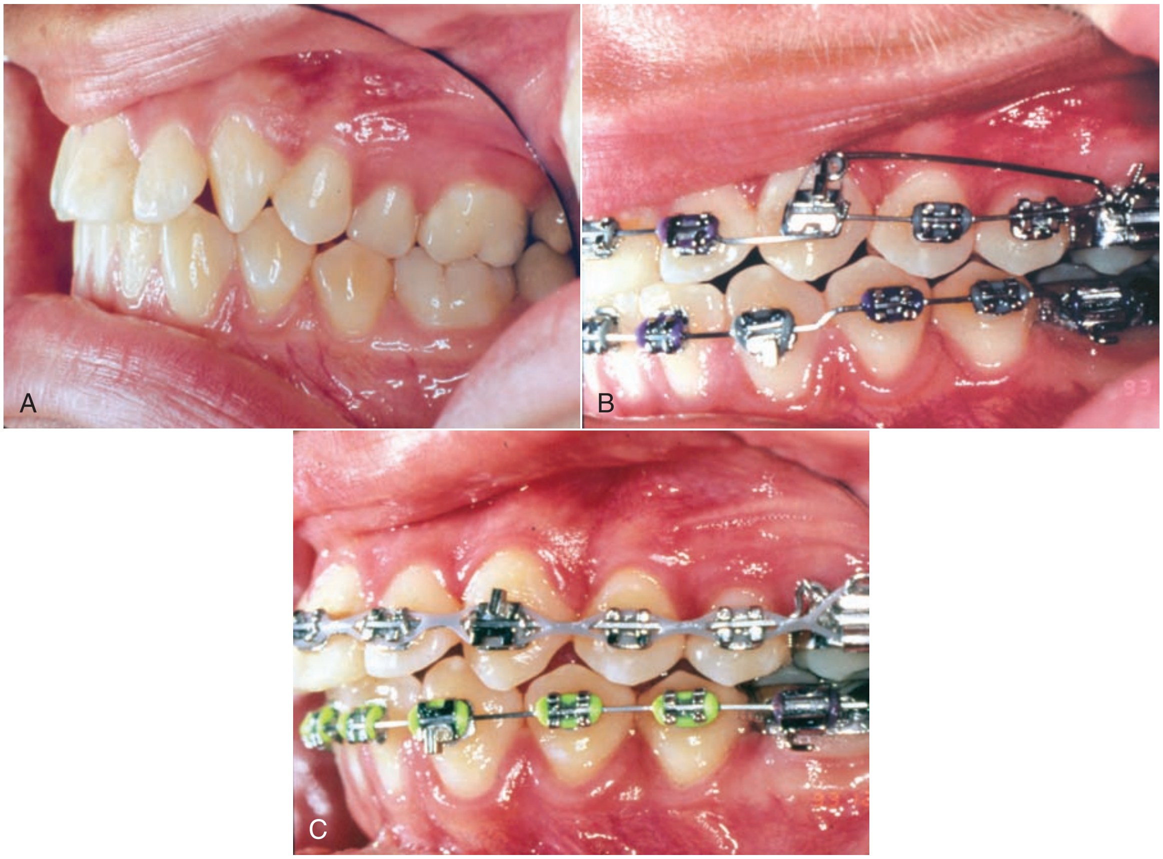


FIGURE 11-39 A 0.017- × 0.025-inch TMA root spring is used to move the canine root distally before final leveling. **A,** Before treatment. **B,** After root correction. **C,** After final leveling.

leveling process. These side effects can be eliminated by the placement of suitable bends, use of bypass arches, and selection of anchorage teeth not adjacent to malaligned teeth.[60,61,73–75] In addition, forming properly designed loops can change a force system from the straight wire.

Figure 11-39, *A*, shows a canine with its root apex forward. A straight wire, as it moves the root distally, also erupts the incisors, producing deep overbite. To prevent this side effect, a bypass arch was constructed. In Figure 11-39, *B*, the continuous 0.018-inch stainless steel arch steps occlusally bypass the canine. The axial inclinations have been corrected by a 0.017- × 0.025-inch TMA cantilever root spring. The reactive forces have been distributed to the whole arch rather than to the incisors. Final leveling can be carried out safely with a straight wire (Figure 11-39, *C*).

With a high canine, as in Figure 11-40, *A*, a straight wire tends to tip the buccal segment toward the canine. To avoid this effect, a bypass arch was formed so that the entire arch was an anchorage unit. A separate NiTi arch from auxiliary tubes on the first molars brought the canine into alignment (Figure 11-40, *B*). Instead of the NiTi secondary arch, a cantilever can be used from the molar auxiliary tube (Figure 11-41).

A 0.018-inch × 0.025-inch TMA wire connects auxiliary tubes on the canine and first molars to torque the root of the canine lingually (Figure 11-42). The long span reduces the torque-twist rate, increasing the range of action and delivering more constant torque. The bypass arch gives full anchorage control.

Teeth other than the canine can be bypassed. With the high central incisor, a straight wire tends to tip the adjacent teeth toward the high incisor (Figure 11-43). A continuous bypass arch with a secondary NiTi wire is used to extrude the incisor without distributing forces to the adjacent teeth.

If a straight wire is used with first molars that are rotated mesially, the side effects can include molar expansion, arch form changes, and prevention of molar distalization. A lingual or transpalatal arch that delivers equal and opposite couples uses reciprocal anchorage and thus more efficiently rotates molars without side effects. This is an example of selecting teeth for anchorage and not relying on a continuous wire that connects adjacent teeth. Connecting only two teeth improves the accuracy of activation. Figure 11-44 shows a 0.032-inch round TMA transpalatal arch that attaches to a precision hinge cap lingual attachment.[76] Equal rotation bends produce equal and opposite couples with no horizontal forces.

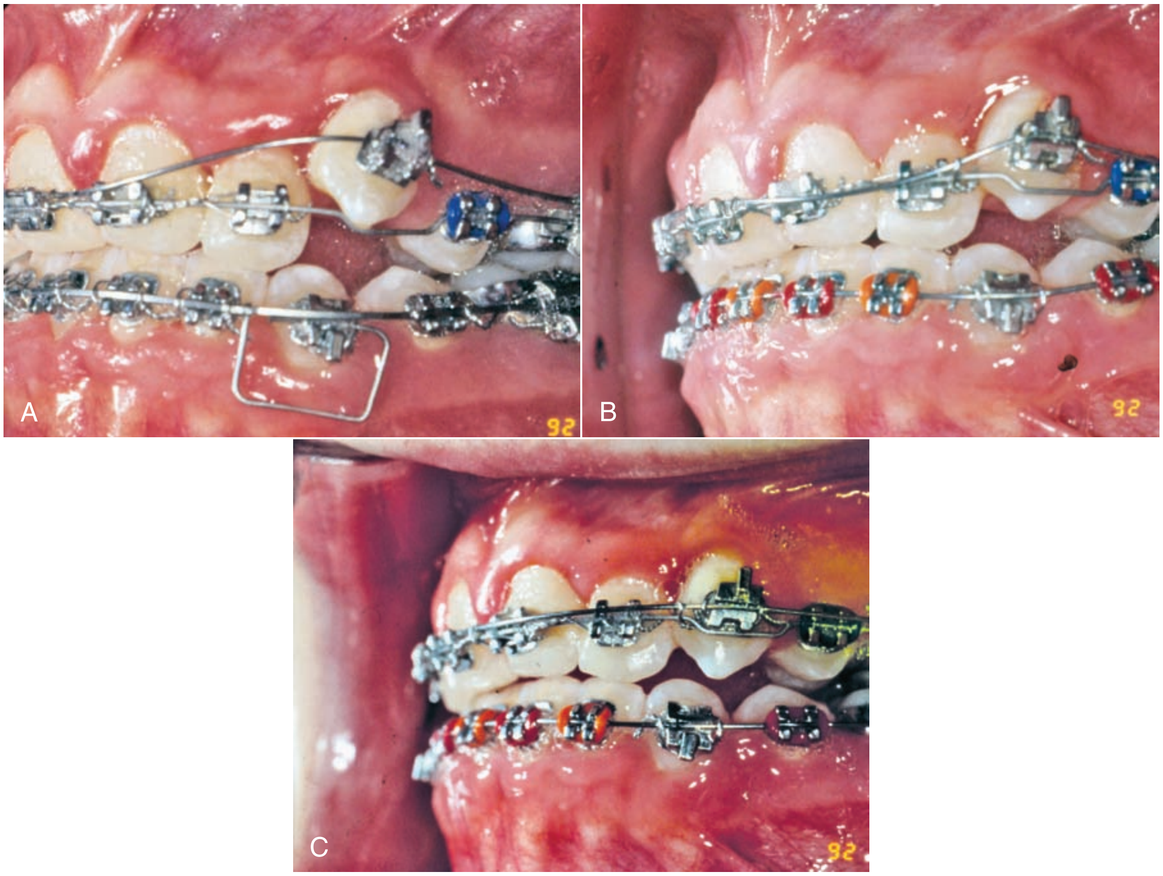


FIGURE 11-40 A cuspid bypass arch prevents side effects. A separate secondary NiTi wire erupted the cuspid. **A,** Before. **B,** Intermediate. **C,** After.

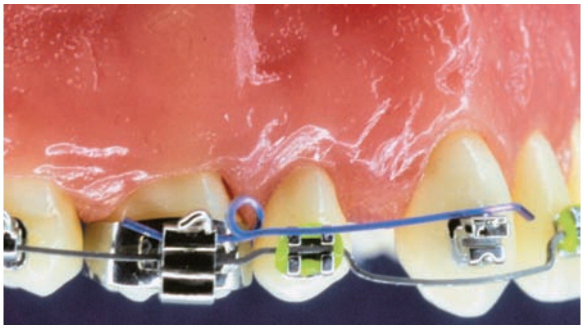


FIGURE 11-41 Canine bypass arch. A cantilever from the molar tube erupts the canine.

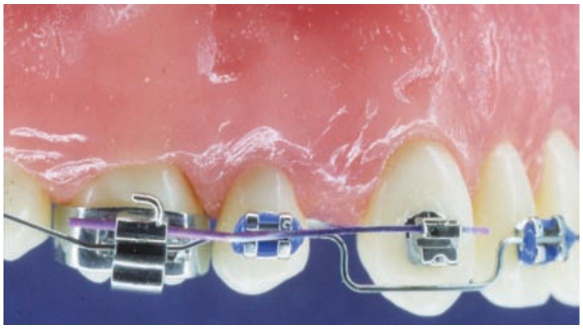


FIGURE 11-42 Canine bypass arch made of 0.016- × 0.022-inch TMA wire torques the canine root lingually. The wire is placed ribbonwise in the canine bracket.

Principles of Spring Design

An understanding of the relationships between bioengineering parameters and force systems can offer a rational basis for the design of orthodontic appliances. To achieve an optimal force system, not only must the force magnitude be correct, but also the force must be delivered constantly and the required M/F ratio must be produced to control the center of rotation. In this section these factors are considered together, using the example of an anterior or canine retraction spring.[57,58,77,78]

For a canine that needs translation, or bodily movement, a force must be applied through the center of resistance of the tooth (Figure 11-45). If the force is 200 *g*, 200 *g* must be delivered at the bracket, as well as a moment of 2000 *g*-mm (provided the distance between the bracket and the center of resistance is 10 mm). In other words, a 10 : 1 M/F ratio is produced. If a simple vertical loop is used for space closure, a moment that encourages the root to move distally is provided during activation. For a loop 6 mm long, the M/F ratio typically is low, about 2.2 : 1.24. This ratio is too low to control the root and prevent it from being displaced mesially. A number of strategies can be used to increase the M/F ratio during activation.[75,79] The loop can be made as long as possible in an apical direction. Increasing the length of the loop to 11 mm approximately doubles the M/F ratio. However, a loop can be extended apically only so far before it causes irritation in the mucobuccal fold. Another strategy involves increasing the amount of wire found gingivally at the top of the loop. Figure 11-46 shows that by increasing the gingival amount of wire (dimension G), the M/F ratio is increased and the load-deflection rate is reduced. One advantage of the T-loop design over a simple vertical loop is that the T-loop produces a much higher M/F ratio to control the root and a low load-deflection rate, thereby ensuring greater force constancy.[77,80,81]

The moment produced by a retraction spring during activation is called the activation moment. The activation moment depends on the change in angle that the horizontal arms of the spring make with the bracket when a loop is pulled apart. Even if the design is improved by use of a configuration such as a T-loop, the M/F ratio may not be high enough to effect translation. To achieve

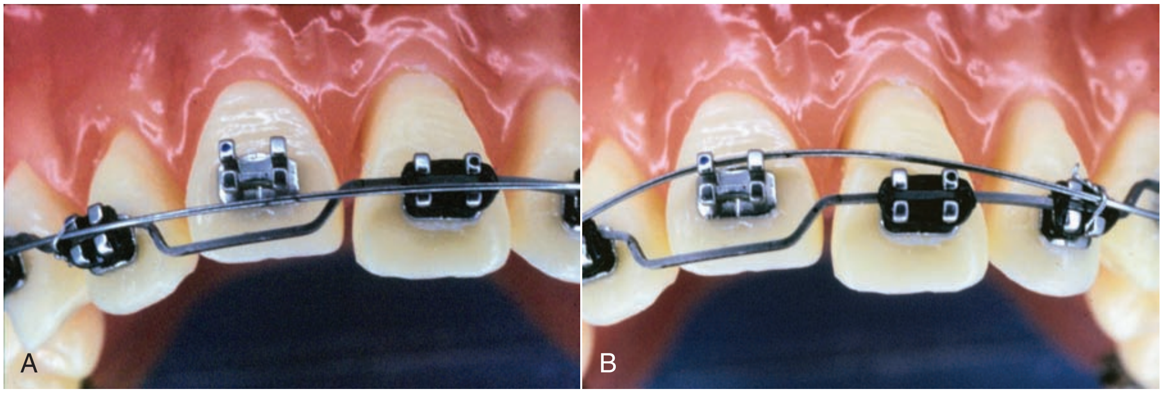


FIGURE 11-43 Incisor bypass arch. A secondary NiTi wire erupts the central incisor without side effects on the adjacent teeth. **A,** Activated. **B,** Passive.

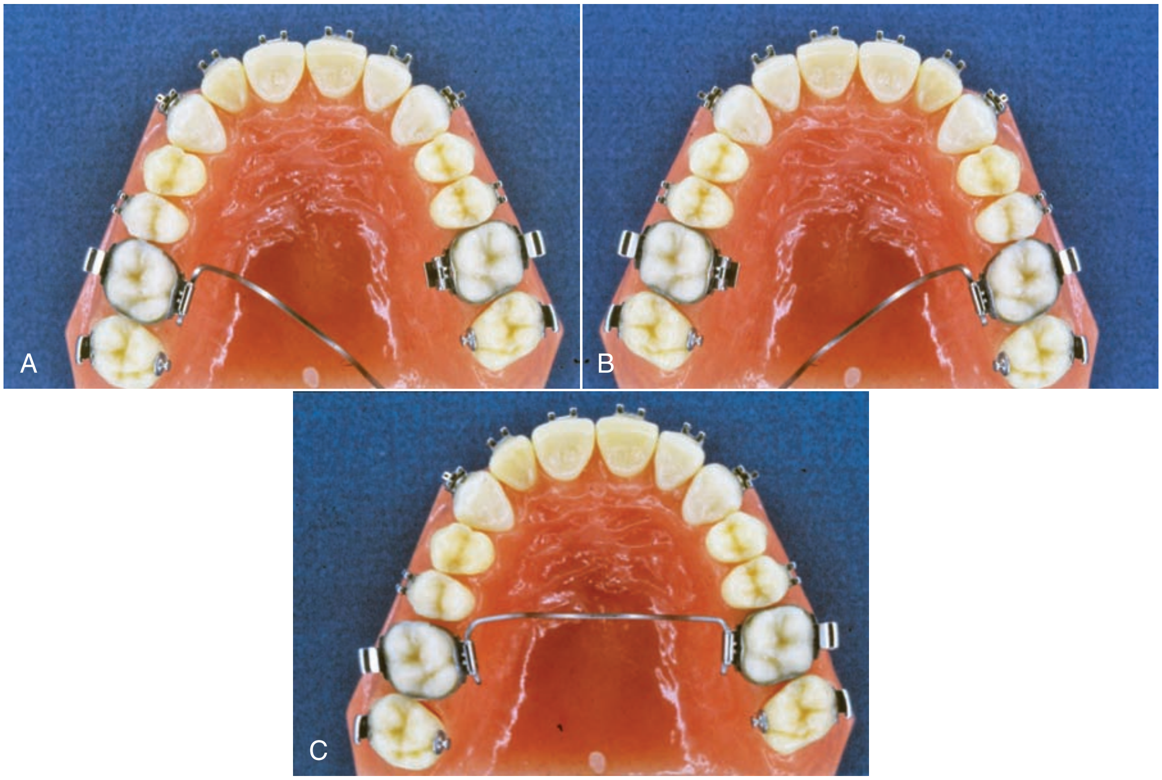


FIGURE 11-44 Precision transpalatal arch produces equal and opposite moments to rotate molars. If both arches are angled equally, no horizontal forces are produced **(A, B). C,** Transpalatal arch inserted showing rotated molars.

a higher M/F ratio, an angulation or a gable-type bend must be put in the spring. The moment produced by gabling is known as the residual moment. Ideally, a retraction spring delivers a relatively constant M/F ratio. If the ratio changes each time the tooth moves, the tooth will not have a constant center of rotation. Two principles to remember in obtaining a constant M/F ratio are to (1) use as high an activation moment and as low a residual moment as possible and (2) lower the force-deflection and moment-deflection rates.

An important factor in the use of a loop for space closure is the mesiodistal position of the loop. If the loop is placed midway between the attachments, equal and opposite activation moments are produced.[79] If the loop is positioned off center to the distal, the posterior teeth receive a larger tip-back moment. In addition, intrusive forces are delivered anteriorly. This concept can be applied in anchorage cases when mesial movement of posterior teeth is not indicated. Conversely, placing a loop mesially off center increases the moment to the anterior teeth and can be useful in bringing buccal segments forward.

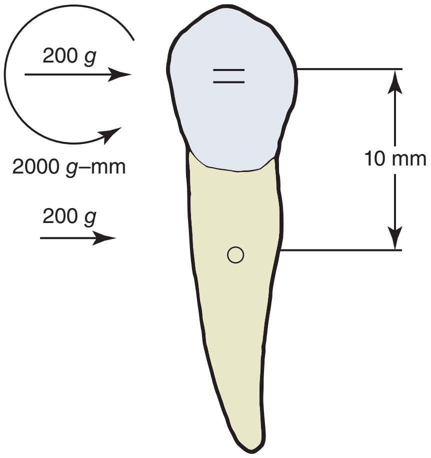


FIGURE 11-45 A force acting at the center of resistance (*CR*) of a tooth translates the tooth. A couple (moment) and a force (*white arrows*) acting at the bracket can produce the same effect. Note that the magnitude of the moment is equal to the force multiplied by the distance from the bracket to the center of resistance. *(Redrawn from Burstone CJ, Koenig HA:* Am J Orthod *70:1, 1976. With permission from the American Association of Orthodontists.)*

Use of a T-loop for en masse space closure is shown in Figure 11-47. Both the anterior and posterior segments are steel; the active T-loop is TMA, which lowers the force-deflection rate and increases the range of activation. The loop (spring) is attached to auxiliary tubes on the first molar and canine. Centering the spring produces approximately equal translation of posterior and anterior segments during space closure. T-loops were used to effect differential space closure, to hold anchorage, and to correct deep overbite (Figure 11-48). The upper loop was placed distally off center. Note that the upper anterior teeth have tipped somewhat lingually; this is to be expected because the moment to the incisors is sufficient to produce only tipping around their apices, not translation. A separate stage of en masse anterior root movement is required after space closure.

One of the problems with using sliding mechanics for canine retraction is the unpredictability of frictional forces. Much of the friction arises from the tendency of the wire to prevent tipping and rotation. In Figure 11-49, a T-loop is used to deliver force during canine retraction. The loop also produces moments that prevent tipping and rotation; hence friction is reduced. Another approach to reducing friction with sliding mechanics is shown in

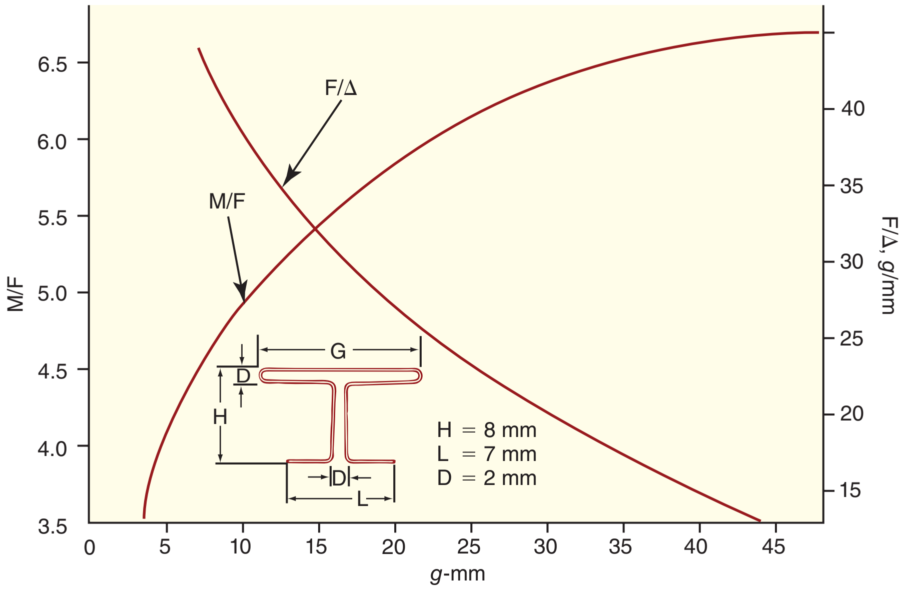


FIGURE 11-46 As the gingival horizontal length increases, the moment-to-force ratio increases and the F/D continues to decrease. *(Redrawn from Burstone CJ, Koenig HA:* Am J Orthod *70:1, 1976. With permission from the American Association of Orthodontists.)*

Figure 11-50; flexible 0.016- × 0.022-inch TMA extensions with helices attached to canine and molar auxiliary tubes place the force closer to the center of resistance of the canine. Unlike rigid "power" arms, the extensions have a relatively low force-deflection rate of 40 *g*-mm and a typical activation of 6 mm.

Fiber-Reinforced Composite Applications

The design of fixed orthodontic appliances historically has required materials with excellent engineering properties as metals and ceramics. Polymers, although user friendly, are structurally weak and hence have limited use, mainly in removable appliances.

A new generation of materials that incorporates long fibers such as glass or carbon has been developed that possesses properties approaching those of metals. To optimize the mechanical properties fibers are wetted, oriented, and the plastic matrix added under controlled manufacturing conditions. Wires or strips that are impregnated by the matrix and are unpolymerized are called "pre-pregs." These wires can be shaped passively to the shape of the arch and when light-cured harden to form a hard and stiff orthodontic component.[82,83]

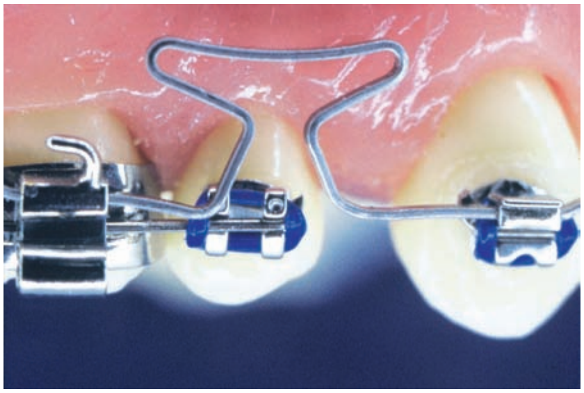


FIGURE 11-47 Centered T-loop is connected to auxiliary tubes on the canine and molar.

The application of a fiber-reinforced composite (FRC) is shown in Figure 11-51. The upper left second molar has tipped forward into the first molar extraction space, and the treatment plan calls for some mesial molar movement to close the space and mesial root movement to correct the axial inclination. Traditionally, metal or ceramic brackets are placed on all the anterior teeth to afford sufficient anchorage. In this patient, a pre-preg composed of long fiberglass and Bis-GMA resin was formed to the shape of the upper arch and then light-cured to form a metal-like rigid, strong, and passive anchorage unit. Attachments were placed only on the second molar and on the FRC in the region of the first bicuspid. A simple wire segment connects the two attachments. The long interattachment span and the use of only a few brackets increase biomechanical efficiency and patient comfort. The correction of the upper second molar axial inclination and space closure is shown in Figure 11-51, *B*. An additional FRC has been placed in the lower arch to facilitate correction of the terminal molar. Following major corrections with a FRC segment, some but not all brackets may be needed for finishing detail.

The development of FRC segments or arches offers a new dimension in appliance design. Anchorage is enhanced because play is eliminated between wire and the bracket. Because these wires accurately fit the teeth, the possibility of undisturbed teeth and a completely passive wire is now possible. In addition, the glass fibers are good for anterior aesthetics.

The Role of Friction

Tooth movement is determined by the total forces applied to the teeth. This includes not only forces from the appliance but also muscular forces that are produced during function. In addition, frictional forces can operate that can considerably alter the force system.

The mechanical principles and their application that govern friction are complicated and beyond the scope of

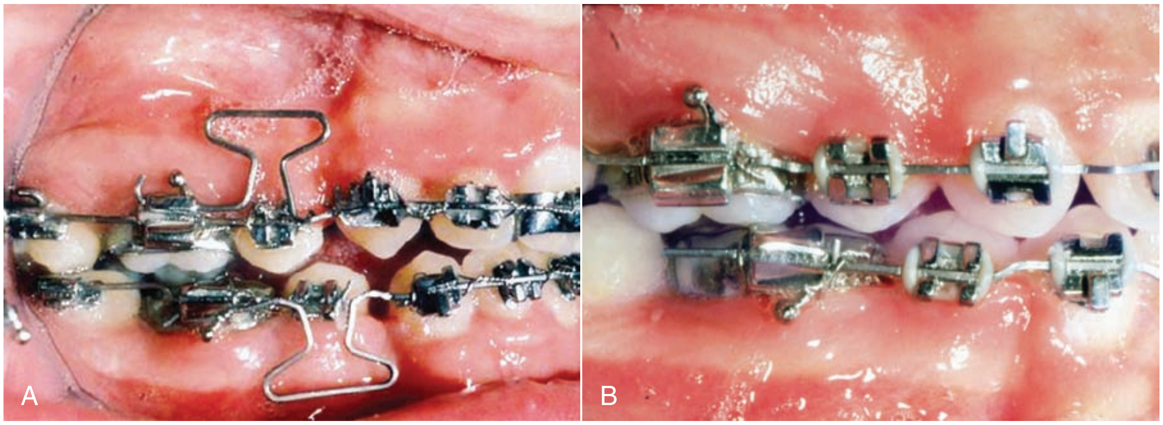


FIGURE 11-48 Differential space closure. Greater tip-back moment was achieved on the posterior teeth by putting the loop distally off center. **A,** After en masse anterior tipping. **B,** After en masse anterior root movement.

this chapter. However, a discussion of some basic principles can be very useful for the clinician. The classic formulas below define a relationship between friction force (F_F), coefficient of friction (μ), and forces operating at 90 degrees to the archwire [i.e., normal forces (F_N)]. M is a moment in loading by a couple and W is the bracket mesial-distal width (Figure 11-52).

$$F_F = \mu \times F_N$$

$$F_F = 2\mu \bullet M/W$$

Thus, friction force is produced by many possible appliance activations: buccal, lingual, apical, and occlusal forces. Friction force is also produced by moments acting on the archwire by "tip" or "torque." The ligation mechanism produces normal forces adding to the friction force. The purpose of ligation is to keep the archwire from being displaced from the bracket. Any additional ligation force will add to the friction force and usually is not desired. The coefficient of friction (μ) is determined by such factors as the material, the material interface if more than one material is used, and lubricants. From an orthodontic perspective, the force system used is the main determinant of the friction force.

Which bracket will produce the most friction force? A narrow or wide bracket? It depends on the stage of tooth movement. If there is initially play between the wire and the bracket, there is little friction—hence, a narrow bracket produces less friction until the wire engages the bracket. Once there is engagement with a single force (e.g., an occlusal force), bracket width does not make any difference if the force magnitude is the same. With "torque" and "tip" moments, for the same magnitude moment, the wider bracket produces less friction.

In special situations as in canine retraction, different stages of tooth movement can be identified during sliding mechanics. Initially, the canine will tip; later, the tooth will translate followed by root correction. Translation requires a larger moment with a distal force and, therefore, frictional forces are greater during the translational stage of retraction. Although there has been much

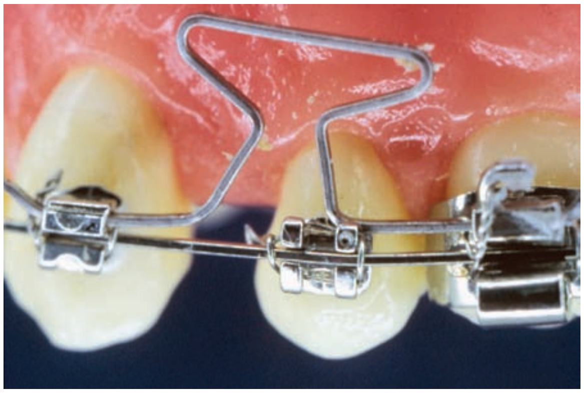


FIGURE 11-49 Canine retraction using sliding mechanics. T-loop moments minimize friction.

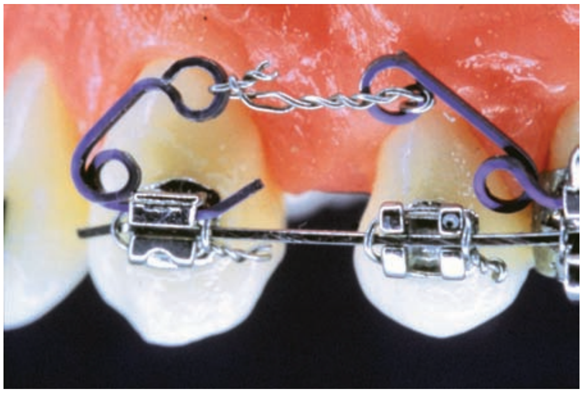


FIGURE 11-50 Canine retraction using sliding mechanics. Flexible extensions deliver more constant force, and the force is closer to the center of resistance of the canine.* *References 35, 84, 85, 87–89.

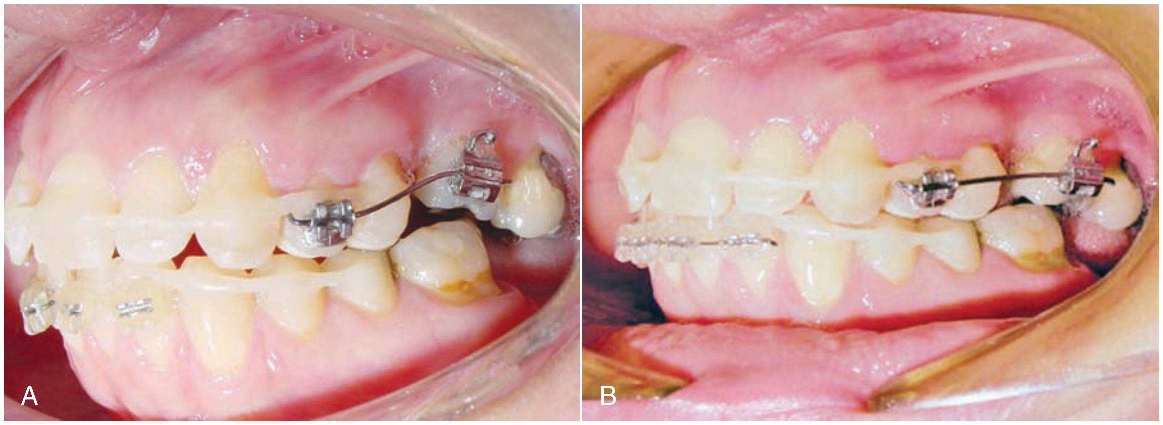


FIGURE 11-51 A fiber-reinforced composite wire (FRC) is used for anchorage instead of brackets to upright the upper left second molar. The aesthetic FRC connects rigidly and passively the anterior teeth. **A,** Before. **B,** After. *(Courtesy Philip Depasquale, Avon, CT.)*

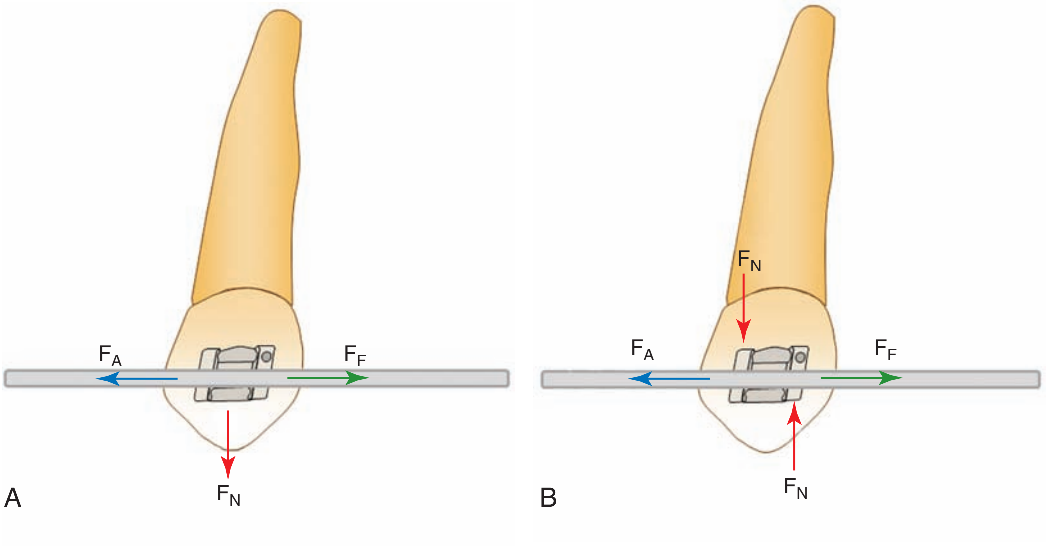


FIGURE 11-52 Normal forces (F_N) in respect to an archwire produce friction forces (F_F). F_A is the applied force. The force the tooth feels is the applied force minus the friction force. **A,** F_N is a single occlusal force. **B,** A couple or pure moment is applied to the bracket of the canine. These normal forces also lead to friction.

discussion about the role of the bracket ligation method as the cause of friction, it should be recognized that most friction is produced by the forces required to correct the malocclusion. Particularly, moments produce large frictional forces since the bracket is far from the center of resistance at the root; hence, for translational or bodily movements, high moments are a necessity.[84]

Friction can be both good or bad depending on the application. With too much friction, force is lost and tooth movement can be reduced. On the other hand, commonly too much force is used and friction reduces the force to more acceptable biologic levels. Friction during space closure can also be helpful in reducing tipping.

When heavier normal forces are applied to an archwire, wire abrasion and indenting can occur. Calculation of the friction force becomes more complicated, and the simple classic formulas are not applicable. It has been demonstrated that vibration or cyclic loading can reduce friction associated with the ligation force.[85]

SUMMARY

Design of an orthodontic appliance requires a thorough understanding of biologic and physical variables. Design is an area in which the concepts of biology and physics can be wedded to form a true biomechanical discipline.

Although the author's purpose is not to attempt a cookbook approach to appliance design, there is merit in pointing out the steps that may go into the design of an orthodontic appliance:

1. The orthodontist as a designer must make certain assumptions about the nature of forces and tooth movement. Objectives relative to tooth movement must be biologically sound, recognizing not only the tissue changes around the tooth but also the generalized growth changes in the face. The biologic objectives of treatment must come first because without them appliance design has no basis.
2. A basic configuration must be selected, depending on the limitations of space in the oral cavity. The configuration should be determined partly by patient hygiene and comfort. Most important, the configuration must be capable of delivering the required force system, should have a desirable maximal elastic load and load-deflection rate, and must deliver the needed M/F ratio. The members should be analyzed so that stress distribution at critical sections does not result in failure.
3. After the general configuration has been established, its dimensions can be determined. Length is established consistent with patient comfort and oral hygiene.
4. When the dimensions of a component are known, the type of material or alloy from which it is to be made can be chosen.[86]
5. Finally, the cross section of the wire is determined.

This is not to suggest that appliances can always be designed by following the same logical sequence. The many variables in appliance design are related and cannot be separated. Furthermore, this list of steps is not meant to suggest that all that is needed in designing an appliance is a group of engineering formulas. Background in the physical sciences can help in the design of appliances, but appliance development still requires a certain amount of intuition, as well as clinical and laboratory experimentation. Basic science, rather than trial and error, offers the greatest possibilities in the development of the orthodontic appliances of the future.

This chapter has discussed the scientific basis of biomechanics and clinical orthodontics. It includes concepts and terminology that are common to physics and engineering. If orthodontists can speak the same language as the physical scientists, they have a better chance to integrate biology and physics as a true science of orthodontic biomechanics is developed.

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CHAPTER 12

Biomechanical Considerations with Temporary Anchorage Devices

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OUTLINE

- **Characteristics and Clinical Significance of Temporary Anchorage Devices**
  - Characteristics of Temporary Anchorage Device Mechanics
  - Clinical Significance of Temporary Anchorage Device Mechanics
  - Considerations for Temporary Anchorage Device Mechanics
- **Clinical and Biomechanical Application of Temporary Anchorage Devices**
  - General Principles in Biomechanical Application of Temporary Anchorage Device Mechanics
  - Molar Intrusion
  - Molar Distalization Biomechanics
  - Molar Protraction
  - Anterior Retraction in Extraction Treatment
- **Case Studies**

CHARACTERISTICS AND CLINICAL SIGNIFICANCE OF TEMPORARY ANCHORAGE DEVICES

Mechanics using temporary anchorage devices (TADs) follow general biomechanical principles, but, compared with conventional mechanics, they have several characteristic features. These features not only make handling treatment with conventional methods easier and more efficient but also make treatment of seemingly impossible cases with challenging anchorage preparation feasible. A good understanding of TAD mechanics with the proper biomechanical treatment principles can minimize side effects while maximizing the efficiency of TAD mechanics.

Characteristics of Temporary Anchorage Device Mechanics

Characteristics of TAD mechanics can be divided into three categories: mechanics using rigid anchorage, intrusive mechanics, and high-efficiency mechanics.[1,2]

Rigid Anchorage. When the TAD achieves bony support via a stable osseous interface, immobile rigid anchorage to the orthodontic load can be supplied within physiologic thresholds. This means that use of a TAD can secure rigid anchorage easily without any additional preparation of the dentition while relieving the limitations of anchorage found with conventional orthodontic mechanotherapy.

Intrusive Mechanics. Conventional mechanics essentially consist of characteristics of extrusive mechanics.[3] Conversely, the TAD is generally located apically compared with the brackets, and in this location, the mechanics are advantageous in achieving intrusion [4,5] (Figure 12-1).

High Efficiency Mechanics. TAD mechanics generally use a single force without moments, which is very efficient for tooth movement[6] (see Figure 12-1). The line of action, point of application, and direction of force can be designed for efficient tooth movement by controlling the location of TAD placement.

Clinical Significance of Temporary Anchorage Device Mechanics

The characteristics of TAD mechanics contribute to the following three features of clinical treatment (see Case Studies 12-1 and 12-2).

Easy and Simple Anchorage Preparation. Orthodontic anchorage can be easily prepared using TADs, regardless of the condition of the dentition. Treatment mechanics can also become simpler. For example, designing mechanics for asymmetric tooth movement is comparatively convenient because the teeth are not providing

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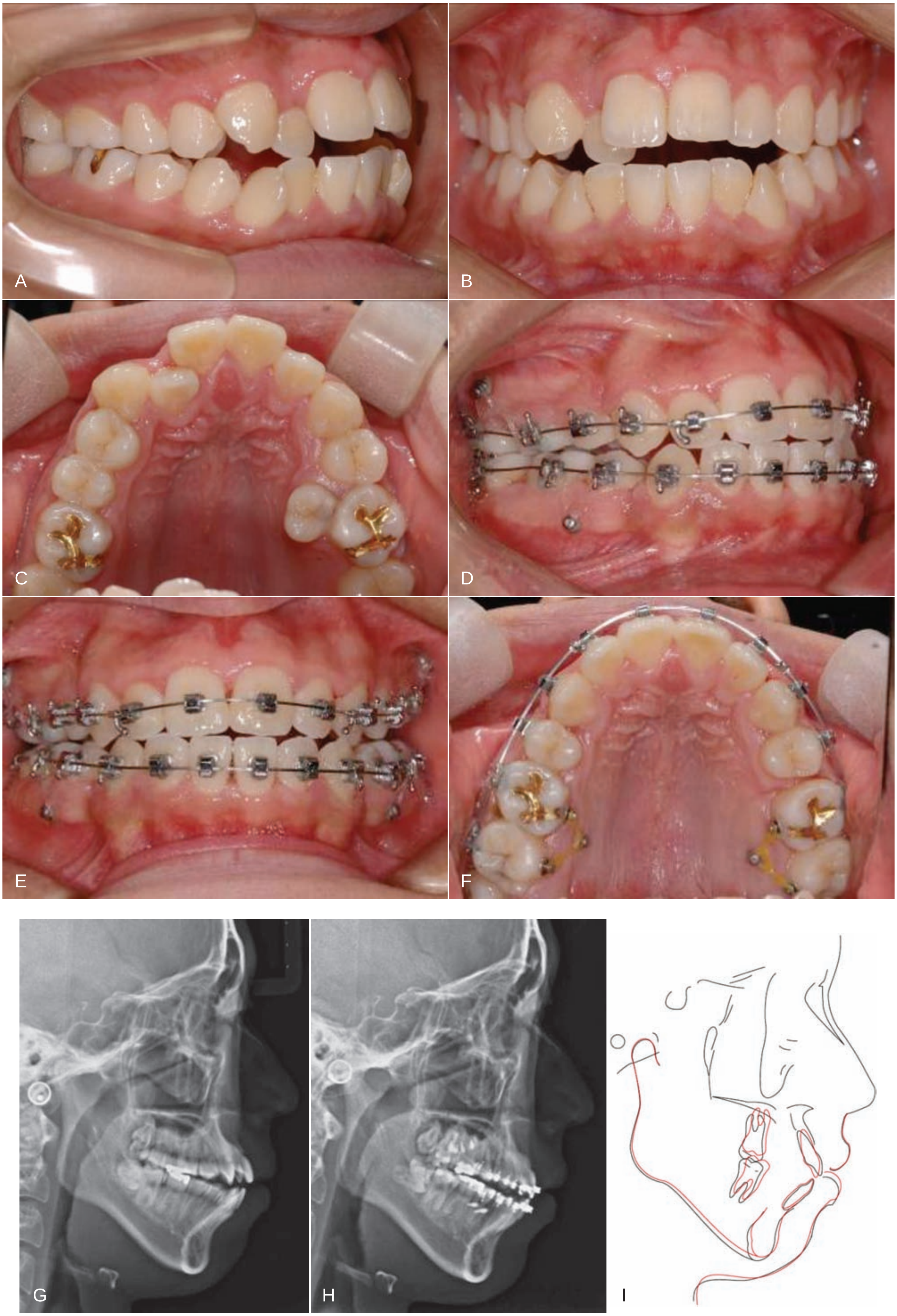

FIGURE 12-1 Buccal and palatal mini-implants were placed and two-single continuous forces without moments were applied for efficient molar intrusion. Cephalometric superimposition shows intruded upper molars and mandible mandibular autorotation. **A–C,** Intraoral views prior to treatment. **D–F,** Intraoral views after 3 months of maxillary molar intrusion. **G,** Cephalometric radiograph prior to treatment. **H,** Cephalometric radiograph after 3 months of molar intrusion. **I,** Cephalometric superimposition.

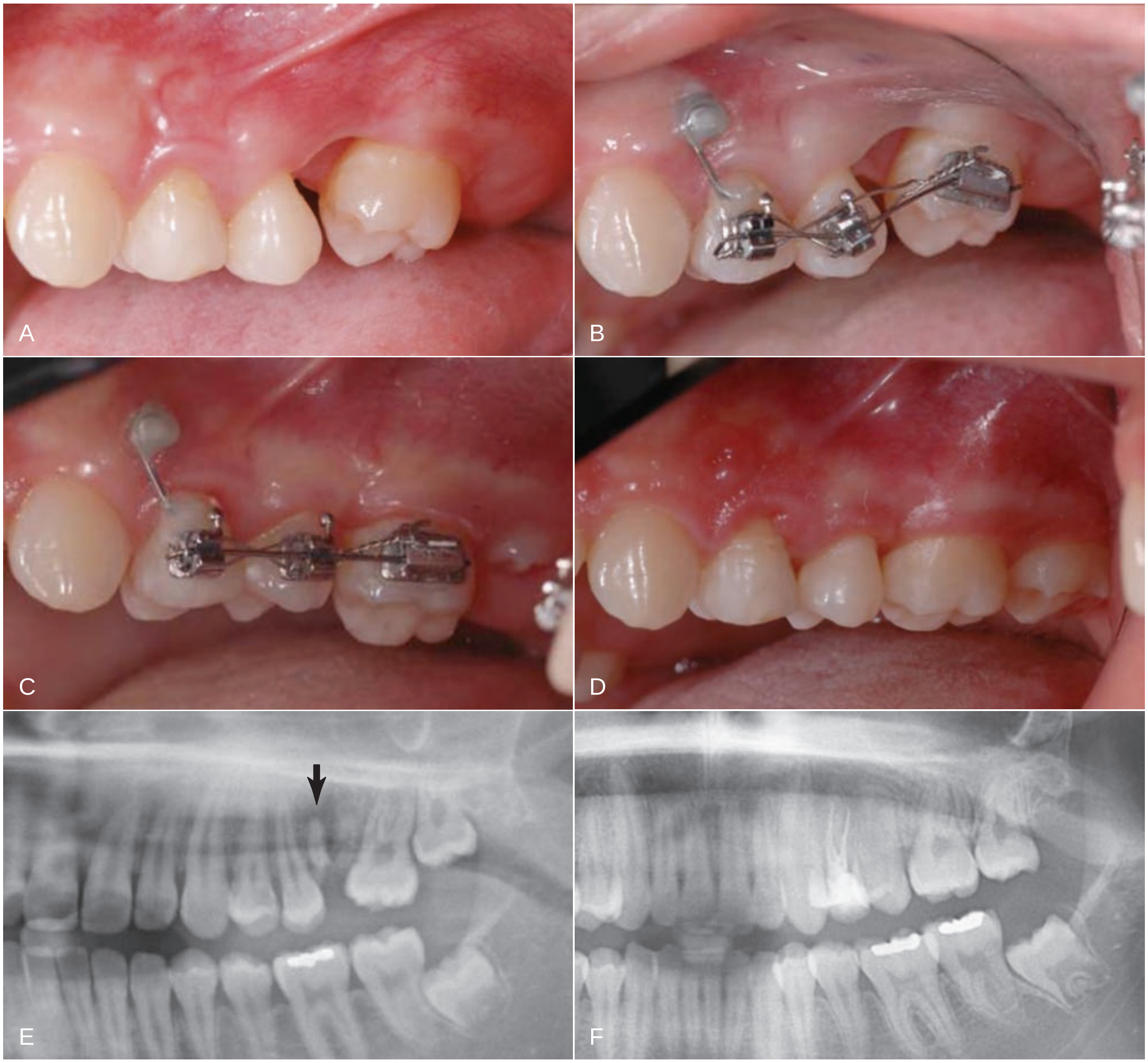

FIGURE 12-2 The mesially angulated second molar was uprighted and protracted to the first molar position with a mini-implant and bonding of sectional orthodontic attachments bonding. The third molar was guided to erupt into the second molar position. **A,** Intraoral view before treatment. **B,** A single orthodontic mini-implant was placed between the canine and first premolar and splinted to the first premolar. First and second premolars and the second molar were bonded and common tied to prevent distal uprighting of the second molar. **C,** The second molar was uprighted and mesially protracted to the first molar position by root movement. **D,** The third molar was guided into the second molar position. **E,** Panoramic radiograph before treatment. Notice the residual roots of the first molar (*black arrow*). **F,** Panoramic radiograph after treatment.

the anchorage.[7–9] Furthermore, adjunctive treatment of tooth loss or impacted teeth can be addressed with the use of TADs and sectional orthodontic attachments (Figures 12-2 and 12-3).

Increase of Treatment Efficiency. Due to rigid anchorage supplied by the TAD, orthodontic treatment can be conducted more easily and efficiently.[10–17] Moreover, mechanotherapy can be designed using a treatment objective centered approach as opposed to a mechanics centered approach. This frees orthodontic mechanotherapy from the biomechanical limitations of anchorage.

Molar distalization becomes simpler and more predictable, even in adult patients, and can be a very useful option for treatment of cases with moderate crowding or camouflage treatment of anteroposterior skeletal discrepancies.[18–24] Furthermore, all of the anterior and posterior teeth can be moved at the same time using rigid anchorage (Figure 12-4).

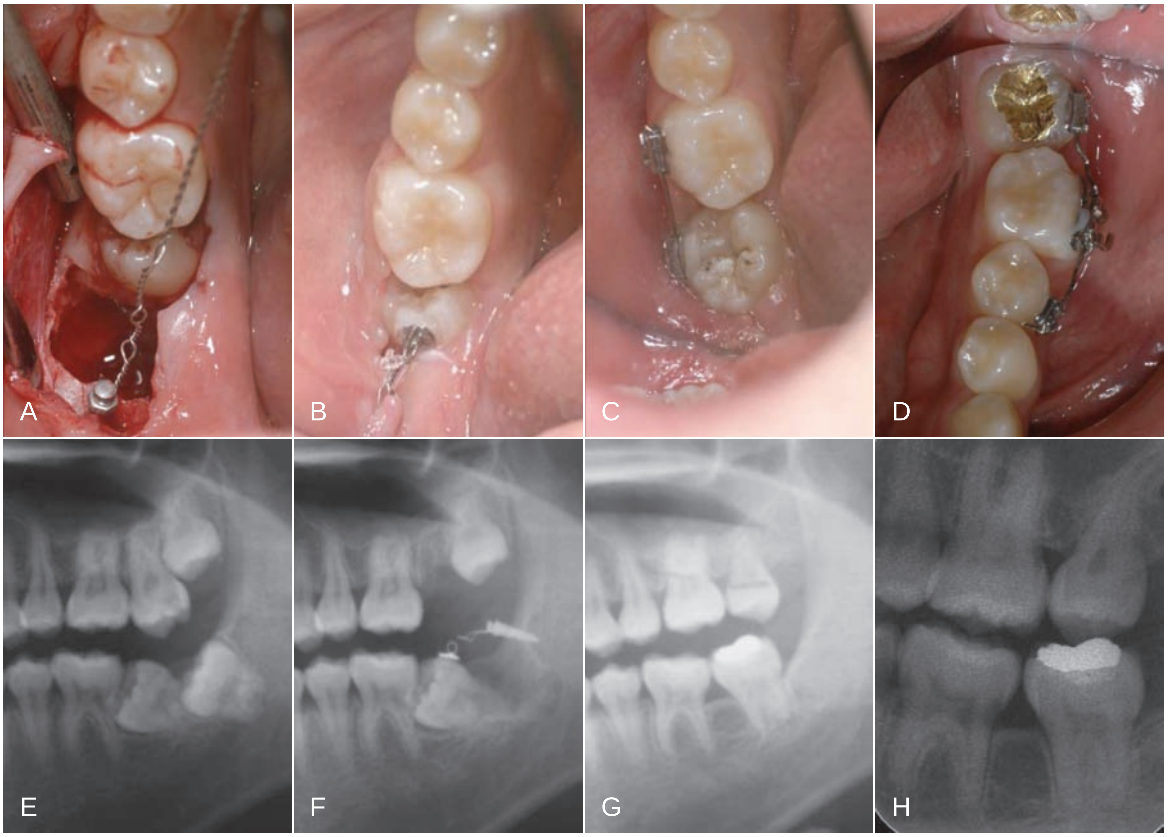

FIGURE 12-3 A 22-year-old female patient had an impacted second molar blocked by the third molar. When the third molar was extracted, a mini-implant was placed on the retromolar area simultaneously. The maxillary second molar was extracted due to supereruption, and the third molar would be guided into second molar position. The mandibular second molar was guided to erupt to the proper position, and the a tube was bonded on the second molar to level and align. The alveolar bone level of the guided second molar was in good condition. **A,** Intraoral view of the extraction of the third molar and TAD placement. **B,** Intraoral view at the start of molar uprighting. **C,** Attachments were bonded on the first and second molar for leveling. **D,** Intraoral view after molar uprighting. **E,** Panoramic radiograph prior to treatment. **F,** Panoramic radiograph while the molar was uprighting with TAD. **G,** Panoramic radiograph at the completion of treatment. **H,** Close-up radiograph shows healthy bone level between the molars.

Expansion of the Range of Orthodontic Mechanotherapy. TAD mechanics can expand the range of orthodontic mechanotherapy. One of the most significant changes is the potential for intrusion of posterior teeth.[6,7–9,25–33] By intrusion of the entire dentition or intrusion of the posterior teeth, orthodontic mechanotherapy can indirectly change the position of the chin point, similar to that seen by surgical repositioning of the maxilla (see Figures 12-4 and 12-5).[6,17,25–27,30,31,33] Additionally, occlusal plane inclination can also be controlled without maxillary surgery when the posterior teeth are intruded. The stability of molar *intrusion is clinically acceptable if proper treatment protocols are followed.*[6,26,27]

Considerations for Temporary Anchorage Device Mechanics

TAD mechanics are useful in solving mechanical problems but have restrictions when addressing the biological limitations encountered with mechanotherapy.

TAD Stability. TAD mechanics is entirely based on the stability of the TAD. The success rate of TADs is greater than 80%, which is clinically acceptable.[34–40] Loosening of a TAD is not uncommon clinically. The more favorable alternative when loosening occurs is to modify the location of TAD placement. However, if the location of the TAD cannot be compromised, a 3- to 6-month waiting period is essential for cortical bone formation before replacing the TAD in the same location.[41–43] In cases of repeated failure, alteration of the treatment plan may be required.

TAD Positioning. Selection of a TAD position is very important for the design of TAD mechanics. In some instances, TADs cannot be placed in a desired position due to limitations of anatomic structures and accessibility. Moreover, TADs placed in interdental areas may restrict tooth movement of adjacent teeth because of the lack of the space between the roots.[44]

Load-Bearing Capacity of the TAD. The orthodontic load-bearing capacity is closely related to the size and

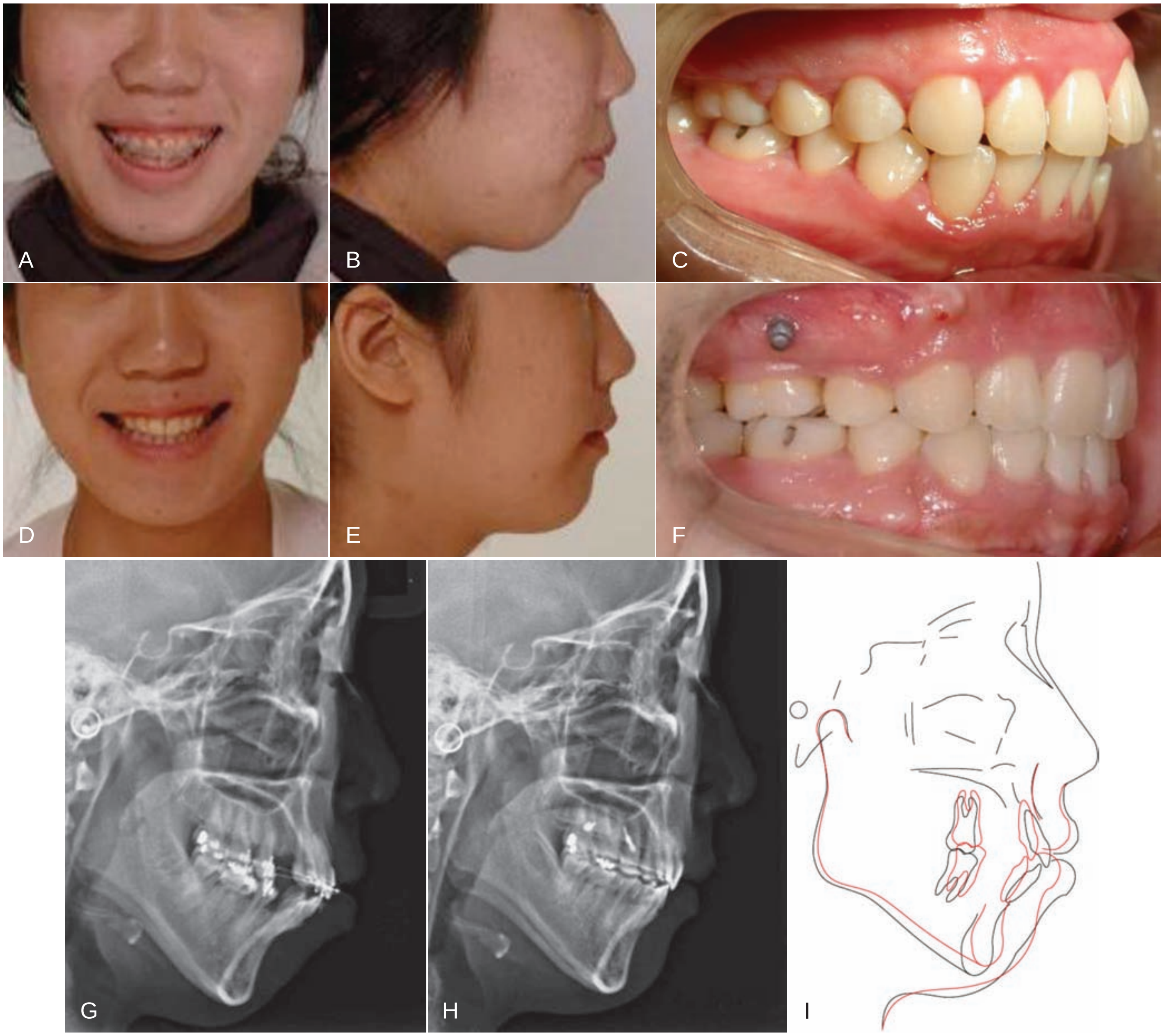

FIGURE 12-4 A 25-year-old female patient had the chief complaint of protrusion of the lips and a "gummy" smile. After four first premolar extractions, anteroposterior and vertical disharmony was improved by anterior retraction and molar intrusion. The chin position was also changed by molar intrusion and subsequent autorotation. **A,** Frontal smile view before treatment. **B,** Lateral facial view before treatment. **C,** Intraoral view before treatment. **D,** Frontal smile view at the completion of treatment. **E,** Lateral facial view at the completion of active treatment. **F,** Intraoral view at the completion of treatment. **G,** Cephalometric radiograph before retraction and intrusion. **H,** Cephalometric radiograph at the completion of treatment. **I,** Superimposition of cephalometric radiograph.

biocompatibility (i.e., bonding strength at the implant–bone interface) of the TAD.[45–47] According to a finite-element model (FEM) analyses study, a mini-screw–type TAD made of titanium alloy can withstand approximately 200 to 400 *g* of orthodontic force depending on the bone condition and diameter of the mini-implant.[6] However, splinting two implants or placing extra implants can allow for heavier forces to be applied.[48] The use of wider and longer TADs may also be helpful.[6,49]

Biomechanical Considerations. The TAD itself can provide favorable orthodontic anchorage but cannot offer an ideal force system for all types of tooth movement. Rigid anchorage is just one of the contributing factors to ideal treatment. However, rigid anchorage itself does not guarantee successful tooth movement; anchorage loss and unwanted side effects can result even with TAD mechanics. For example, the intrusive force vector of TAD mechanics can produce side effects

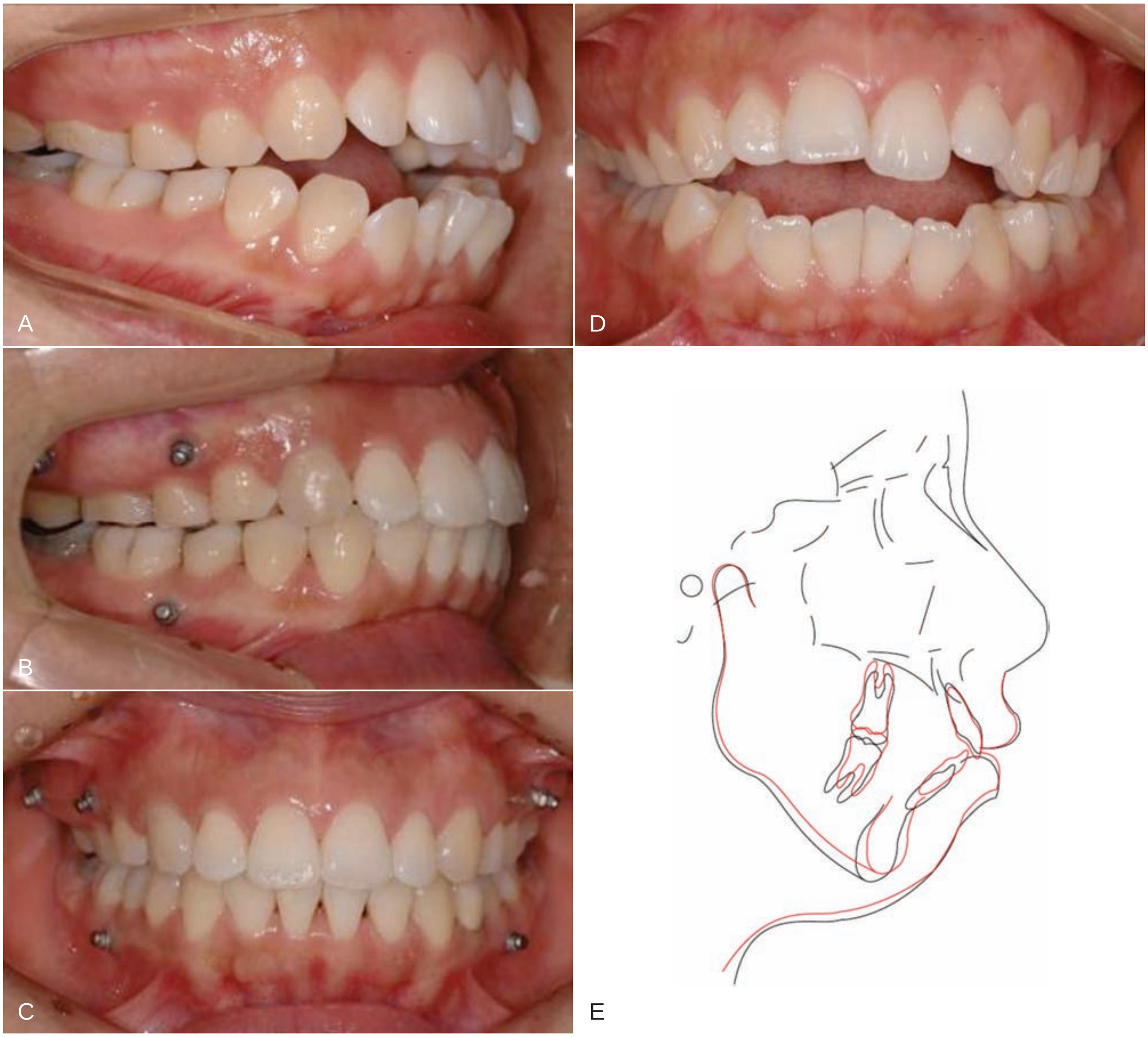

FIGURE 12-5 A 25-year-old woman presented with an anterior open bite. Using maxillary buccal and palatal and mandibular buccal TADs, the molars were intruded and the vertical excess problem was improved. The chin moved upward and forward. **A, D,** Intraoral view prior to treatment. **B, C,** Intraoral view at the completion of active treatment. **E,** Cephalometric radiograph superimposition.

unforeseen with conventional mechanics (Figures 12-6 and 12-7). These consequences are very difficult to correct. Therefore, it is necessary to remove or control unwanted force vectors from the TAD in all three dimensions of space.

Biological Limitations as a Fixed Mechanotherapy. TAD mechanics move teeth using the same principles as conventional mechanotherapy and must be used with consideration to biological limitations. Tooth movement should take place within the periodontal complex,[50–54] as with all mechanotherapy.

Although research and clinical trials have been reported,[55–58] a clear protocol of the orthopedic effects to the basal bone using TAD mechanics is not yet established. Further studies are needed to clarify the orthopedic effects of TAD mechanics. With regard to transverse orthopedic expansion, several studies to expand the lateral envelope of movement of the posterior teeth have been conducted,[59–62] but no definite conclusions have been established.

Side Effects Related to TAD Mechanics. Unexpected iatrogenic side effects such as root injuries and penetration into the nasal cavity or maxillary sinus may occur during surgical placement of the TAD.[63,64] Root injuries are reversible in many cases[65–68]; however, a crack to a root is considered irreversible.[6] Proper

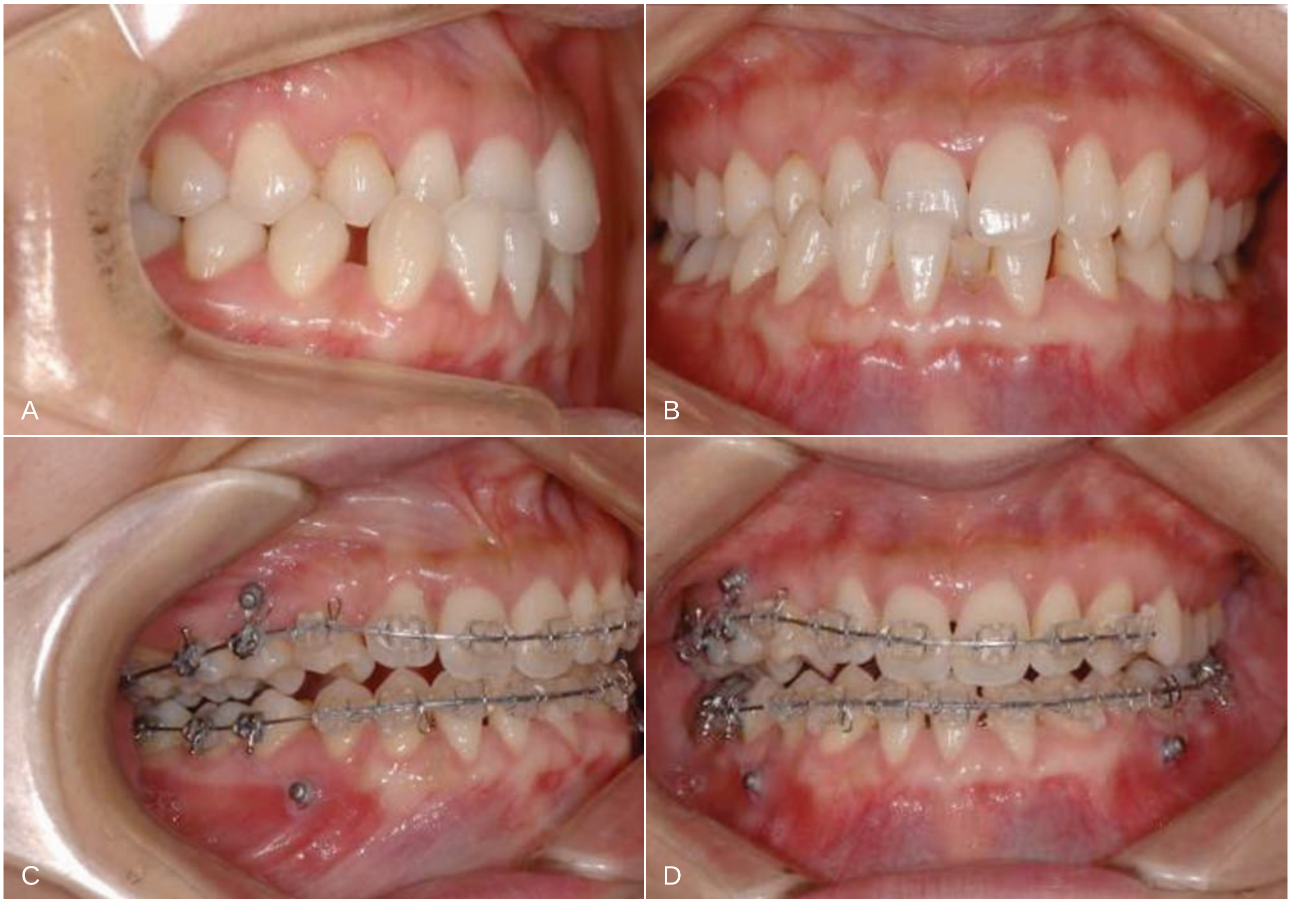

FIGURE 12-6 Orthodontic force was applied to protract the molar unilaterally from the TAD to close the space of the upper right deciduous canine. However, an open bite resulted due to mesial tipping of the molar as well as the intrusive force vector in the premolar area. Using lever arm mechanics, intermaxillary elastics can prevent such side effects and can solve the problem. **A, B,** Intraoral views prior to treatment. **C, D,** Intraoral views during treatment. Occlusal canting developed.

surgical protocols can prevent iatrogenic injuries to anatomic structures.[6,69]

TAD mechanics can expand the envelope of discrepancies of tooth movement, but may also contribute some negative aspects.[52] Side effects, which are related to intrusive mechanics and are not common to conventional mechanics, can develop. Additionally, TAD mechanics may worsen the conventional side effects of orthodontic treatment. Root resorption and periodontal problems, particularly, may occur due to large amounts of tooth movement using rigid anchorage. Side effects resulting from misdiagnosis and overtreatment should be avoided.

TAD mechanics can also increase the expectation level of patients and may cause further dissatisfaction in a subjective patient. For satisfactory and successful treatment, the operator should engage in thorough communication with the patient regarding the effectiveness and limitations of the TAD.

CLINICAL AND BIOMECHANICAL APPLICATION OF TEMPORARY ANCHORAGE DEVICES

General Principles in Biomechanical Application of Temporary Anchorage Device Mechanics

Establishment of an Individualized and Optimal Treatment Plan. The individualized treatment plan should be determined by collecting an adequate database of information with regard to the patient and interviewing the patient and any persons concerned.[70] Cost-benefit analyses should also be considered when deciding between treatment options.

The Selection of a TAD System and an Insertion Site. Various TAD systems are available on the dental market,[71,72] and there are numerous reported clinical applications. A specific TAD system and insertion

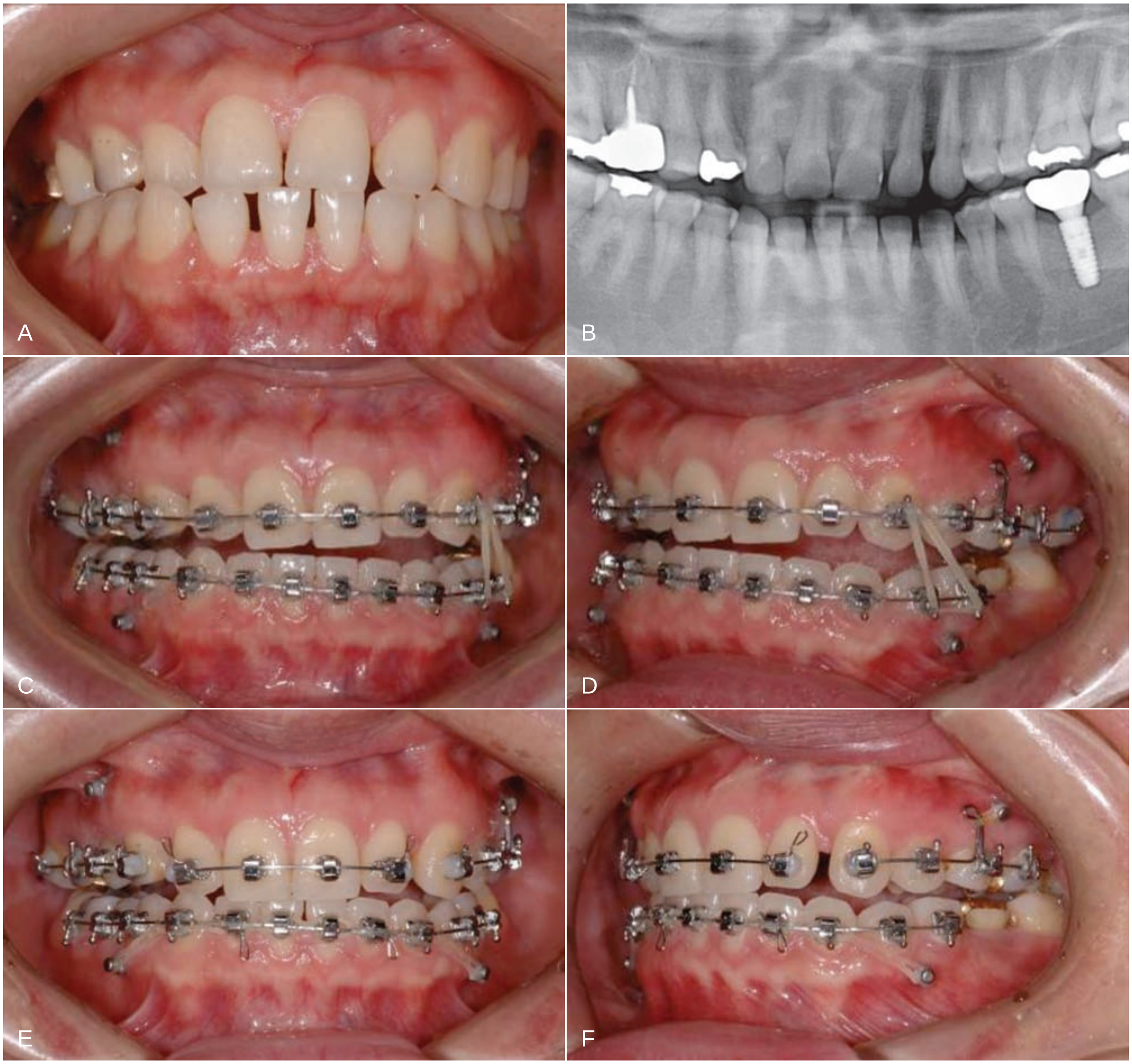

FIGURE 12-7 Bilateral, symmetric retraction and intrusive forces were applied, but occlusal canting developed due to different anchorage values on either sides. That is, there was more intrusion on the left anterior area because the left first molar prosthodontic implant was not included in the full bonding. Using intermaxillary elastics, canting was improved. Conventional extrusive mechanics are useful to compensate the disadvantages of the intrusive components from TAD mechanics. **A,** Intraoral views prior to treatment. **B,** Panoramic radiograph prior to treatment. **C, D,** Intraoral views during treatment. Occlusal canting developed. **E, F,** Intraoral views during the canting correction.

site should be selected according to the individual treatment plan.

Anatomic Factors. The cortical bone must be thick enough to provide sufficient primary stability (mechanical stabilization from cortical bone immediately after implantation), and thus adequate cortical bone is required for early stability and favorable healing.[73–75] Edentulous areas have low bone quality, sometimes due to atrophy. In these areas, bone probing is necessary following anesthesia to check the quality of cortical bone.

Attached gingiva is not always necessary for TAD maintenance[35] but is more favorable compared with the oral mucosa. However, the stability may be compromised if the TAD is irritated by the oral mucosa and can lead to unfavorable conditions as well.

TAD placement in areas where significant stress is applied should be avoided when possible. For example, stability of a TAD near the mandibular first molar may be compromised[34,39] due to masticatory stress. Good accessibility during surgical placement is advantageous

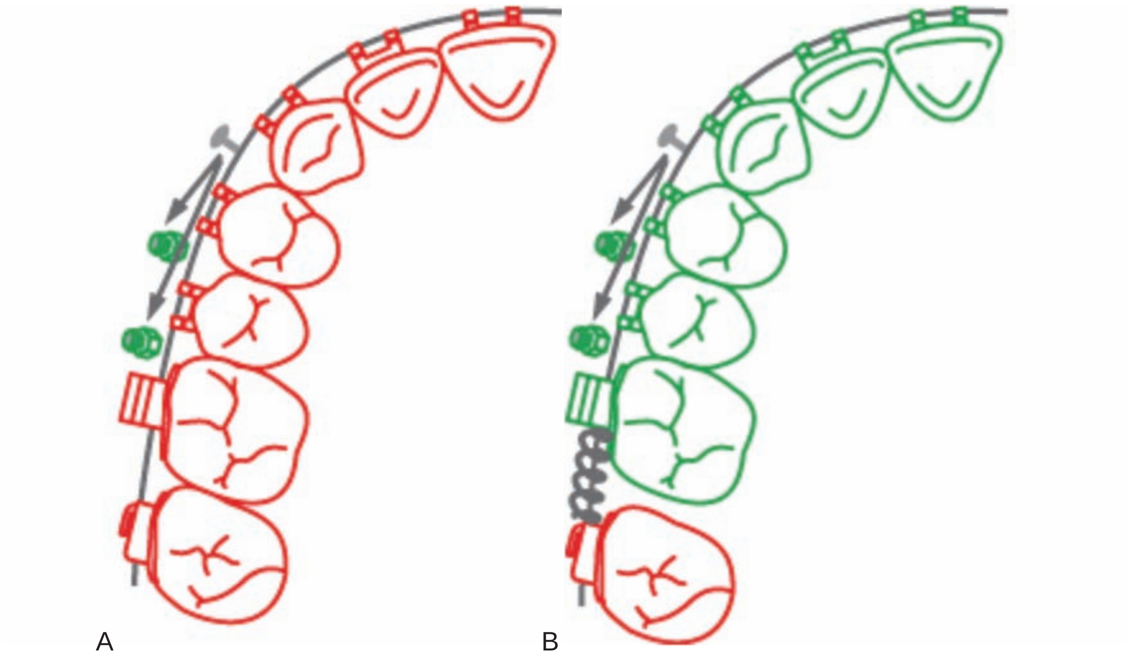

FIGURE 12-8 There are two methods for molar distalization: the entire dentition can be distalized **(A)** or the second molars can be moved distally first and with the rest of the dentition following **(B).** When the entire dentition is distalized, only TADs provide anchorage for movement of all the teeth. On the other hand, when only the molars are moved distally first, the rest of the dentition and the TADs both provide anchorage. When distalizing the entire dentition at once, treatment mechanics may be simpler and treatment time shorter. However, there is also less treatment predictability as more teeth are involved. Conversely, when distalizing the molars separately, it is more predictable due to more anchorage and less teeth being moved. But, more steps in treatment processes are needed and it will make treatment more complex. (*Green* indicates an anchorage unit; *red*, a unit to be moved.)

in achieving primary stability. Risks of irreversible injury to important anatomic structures should be minimized. Furthermore, the TAD itself should not be an obstacle for planned tooth movement.

Biomechanical Factor. The TAD should be placed in a biomechanically suitable position for planned tooth movement. Moreover, the TAD position must be primarily favorable for the main target tooth.

Clinical Factor. Pain and discomfort following surgical placement of TADs are clinically acceptable.[76,77] Furthermore, the TAD should be placed in areas that result in minimal discomfort for the patient during treatment.

Treatment Strategy. First, to efficiently achieve treatment objectives, a strategy should be planned (Figure 12-8). The priority of tooth movement should be decided before instituting a plan to move the target tooth. In other words, the teeth to be moved and the establishment of an anchorage unit at each stage of treatment should be identified before movement begins.

Design of Mechanotherapy. To obtain the desired tooth movement according to the treatment strategy, mechanics with an optimized orthodontic force system should be designed (Figure 12-9). During this process, two things need to be considered: how to produce tooth movement and how to control this movement.

With regard to producing tooth movement, the operator needs to determine what kind of orthodontic force system will be used. The force system of the mechanics at the start of treatment and any changes in the force system that come about when the tooth is moving are important, which is related to mechanical efficiency and to the speed of tooth movement. This is especially imperative in difficult types of tooth movements.

The operator should also decide how to control the teeth three-dimensionally during treatment. There are unwanted movements that occur as treatment progresses, even in an ideally designed force system. For successful application of TAD mechanics, proper monitoring and three-dimensional adjustments should be made upon tooth movement. There are several different ways to make such modifications: the use of a single force with or without an additional TAD, the use of brackets and wires, and the combination of both.[6]

More specifically, there are two types of mechanics that can be used (Figure 12-10): force-driven mechanics, which uses just a single force, and shape-driven mechanics, which uses the shapes of the archwires engaged in the brackets.[78]

Force-driven mechanics have a statistically determinate force system, whereas shape-driven mechanics have a statistically indeterminate force system. From the

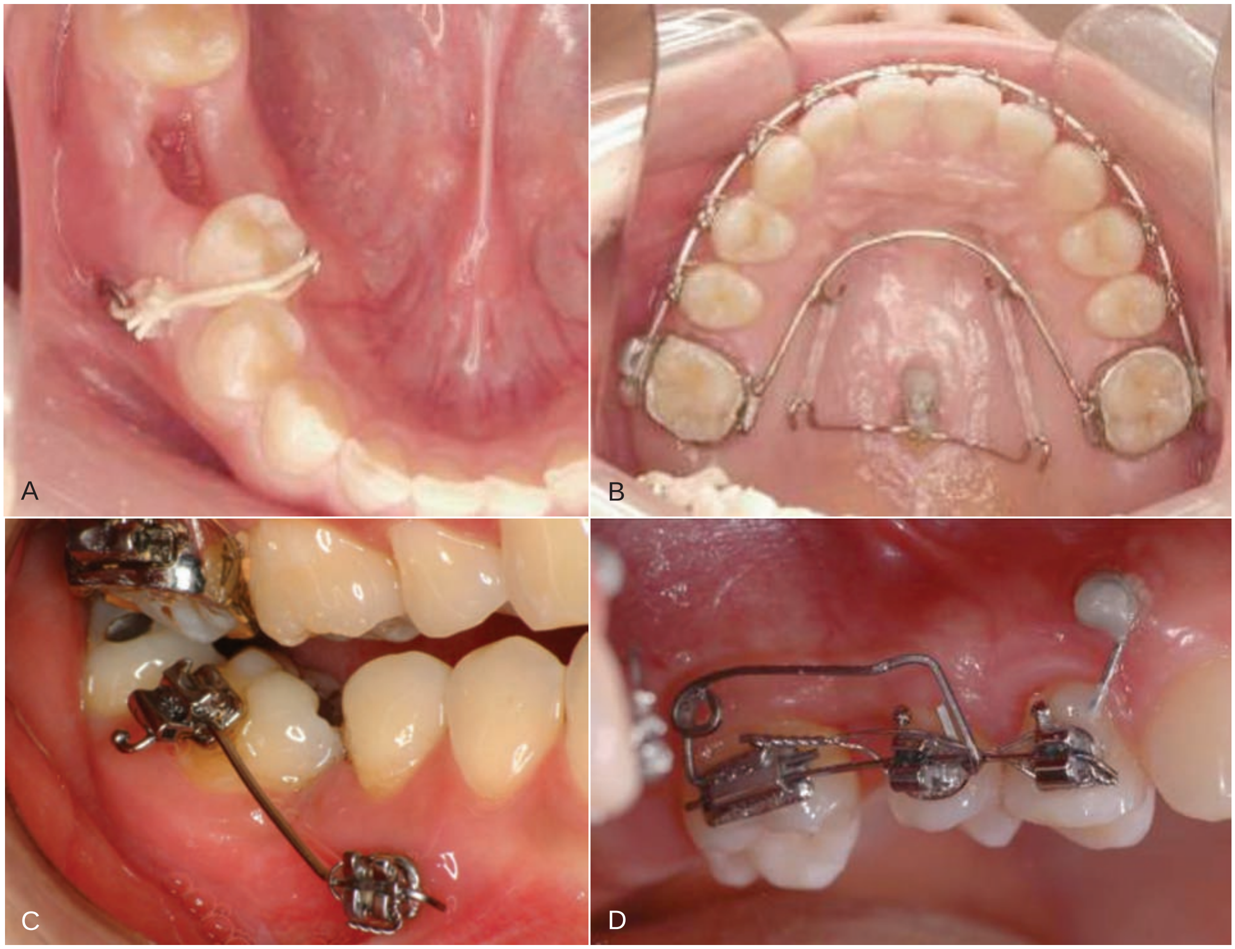

FIGURE 12-9 Diverse methods to use a TAD. **A,** *Direct application of a single force:* When using a single force, precise calibration is possible. Moreover, the whole force system does not change significantly even as the tooth is moved. To control the tooth movement, the line of action should be adjusted. **B,** *Indirect application of a single force:* Using attachments on TADs, the line of action can be controlled. **C,** *Direct application of force and moment:* If wires can be engaged to TADs, TADs can produce not only a force but also a moment. When the wire attached to the TAD is engaged into the bracket slot at the opposite side, it becomes a statically indeterminate force system and the force system cannot be predicted precisely. When the tooth is moved, the total force system will be altered as well. Additionally, complex use of a TAD can negatively affect its stability. **D,** *Indirect application of force and moment:* The combination of a TAD and tooth can be considered a total anchor unit. It can provide three-dimensional anchorage, but there is little movement of the anchorage unit. When using this unit for an indirect application, the operator has to take into consideration that the tooth with a PDL can be moved but the stable TAD with an osseous interface cannot be moved. This means that if the TAD is splinted with a wire of higher stiffness to a tooth receiving heavier occlusal forces, there will be a detrimental effect to the stability of the TAD.

standpoint of efficiency, force-driven mechanics are more advantageous because the force system can be designed precisely and does not change significantly even with tooth movement.

The force system of shape-driven mechanics cannot be designed precisely and changes significantly with tooth movement because it is a statistically indeterminate force system. Therefore, shape-driven mechanics are not efficient in cases of difficult types of tooth movement such as molar intrusion. However, shape-driven mechanics are more effective in detailed adjustments of tooth positions clinically.

Molar Intrusion

Decision-making. When considering the effects of molar intrusion[6,25–33,70,79–90] (Figures 12-11 and 12-12) to decide whether a molar should be intruded, three major factors should be evaluated.

Local Factors. The intermaxillary occlusal relationship should be considered. The condition of alveolar bone and attached gingiva should also be evaluated.

General Factors. In addition to occlusal relationships, facial and smile esthetics should be assessed. To reduce lower facial height, the upper and lower dentition

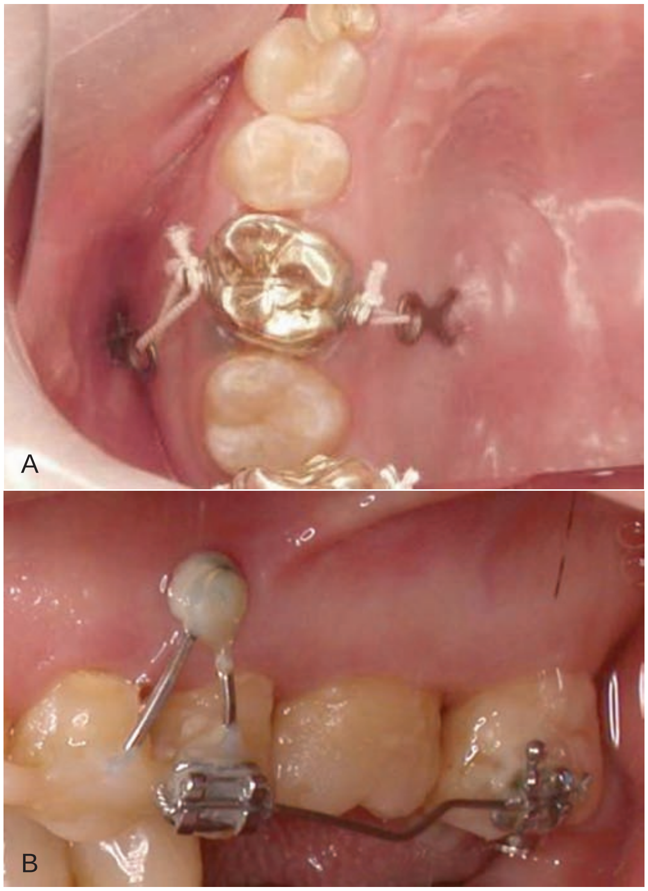

FIGURE 12-10 Molar intrusion can be achieved by force-driven mechanics **(A)** or shape-driven mechanics **(B). A,** Force-driven mechanics use only single forces without moment. **B,** Shape-driven mechanics use continuous archwires, which are engaged into the brackets. As a consequence, forces and moments are produced and they cannot be calculated chairside.

should be controlled at the same time; if only one arch is intruded, unwanted extrusion of posterior teeth occurs in the opposing arch.[6,26,27,30]

Factors for Stability. Stability of molar intrusion and anterior facial height reduction can be achieved by overcorrection.[6,30,82] For retention of an anterior open bite correction, functional improvement of the musculature following treatment is essential.[6,26,27,30,91–95] Tongue thrust during swallowing should especially be controlled for increased stability.[6,93–95]

Biomechanics.

Mechanical Efficiency. Molar intrusion is one of the most difficult tooth movements to achieve. Therefore, mechanical efficiency is very important in the design of molar intrusion mechanics. That is, force-driven mechanics should be included considering its efficiency and predictability (Figure 12-13).

Three-dimensional Control. Mechanics for posterior intrusion should be designed to achieve three-dimensional control of the molar and the molar must be monitored in all dimensions during movement (Figures 12-13 through 12-16).[6] More specifically, rotations, tipping, torque, mesiodistal positioning, and inferosuperior positioning of the tooth all need to be controlled. Arch form, inclination of the occlusal plane, and the frontal occlusal plane should also be evaluated.

As mentioned previously, there are several ways in which three-dimensional control can be managed: the use of a single force from the TAD, the use of brackets and archwires, and both of these methods combined (see Figure 12-16). For example, the use of a single force generated from a TAD in an appropriate position (i.e., force-driven mechanics) is more effective for gross control.

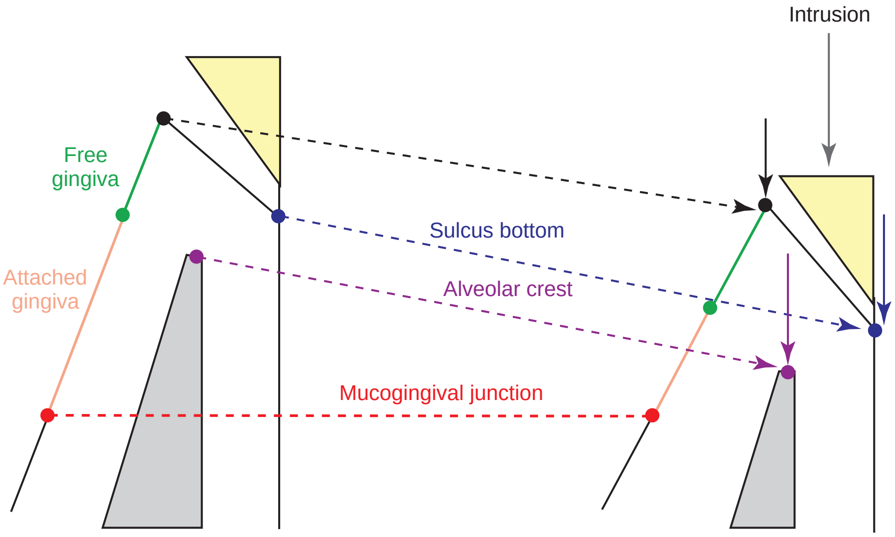

FIGURE 12-11 Local effects of molar intrusion: As the molars are intruded, the alveolar bone crest and free gingival margin move together eventually if there is proper oral hygiene control. But the mucogingival junction is not changed, so the width of the attached gingiva decreases.

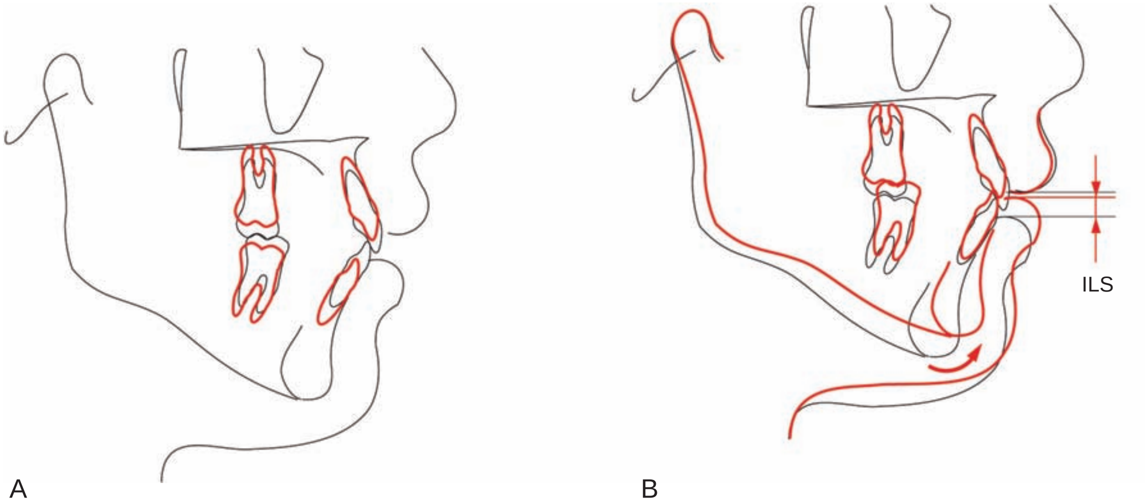

FIGURE 12-12 *General effects of molar intrusion:* After molar intrusion **(A),** the mandible rotates around the horizontal condylar axis to align itself to maintain interocclusal rest space. Consequently, the chin moves upward and forward and the interlabial space (ILS) at rest decreases **(B).**

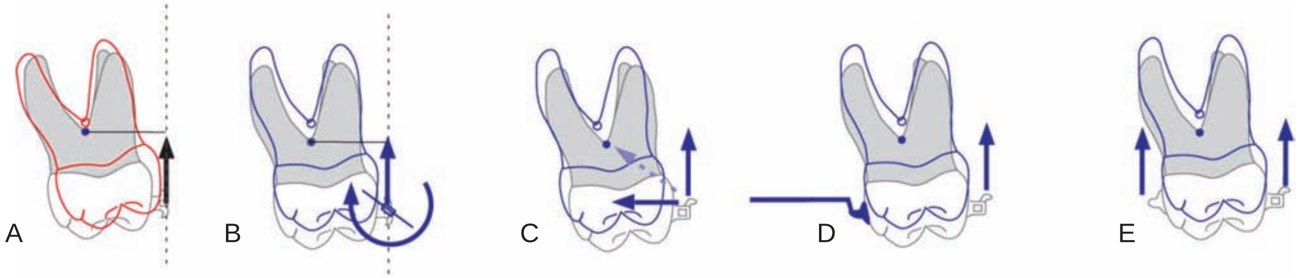

FIGURE 12-13 *Posterior torque and arch form control during molar intrusion:* Posterior torque and arch form (buccolingual positioning) control are related. **A,** Buccal intrusive forces away from the center of resistance cause buccal tipping and arch expansion. **B,** Lingual crown torque may be used to offset the tendency of buccal tipping for bodily movement. However, it is difficult to calculate the precise amount of moment (palatal crown torque) needed. Theoretically, even if palatal crown torque is applied precisely, slight tooth movements can generate changes to the force system, rendering it biomechanically inefficient. In order to apply lingual crown torque, the archwire can be torqued or brackets with sufficient lingual crown torque can be used. **C,** In the case of using buccal intrusive forces, a constriction force can be applied to reduce the tendency of buccal tipping. The degree of constriction force should be similar to that of the intrusion force, but this force system is difficult to control precisely. **D,** An active or passive transpalatal archwire (TPA)/lingual archwire (LA) is effective for controlling torque and arch form. However, these appliances may be uncomfortable for patients while lowering the rate of tooth movement as well. **E,** Labial and lingual combined intrusion forces are most effective for torque control. This system can also control the arch form.

Treatment Mechanics.

Maxillary Molar Intrusion. Palatal root control is important for upper molar intrusion because the center of resistance of the maxillary molar is located on the palatal side.[96] A palatal intrusion force is very effective for palatal root control and for an increase in biomechanical efficiency.

Mandibular Molar Intrusion. Mandibular molar intrusion is different from maxillary molar intrusion; biologically, the mandible is composed of harder and denser bone, contributing to a slower bone turnover rate. Clinically, the success rate of a mini-screw–type TAD placed between the mandibular molars may be lower than a TAD positioned between the maxillary molars.[34,39] The mandibular lingual area is especially difficult for TAD insertion.

However, lingual intrusive forces are of less necessity in mandibular molar intrusion than in maxillary molar intrusion because buccal intrusive forces in the mandible produce less buccal tipping. This is due to the fact that there is more lingual inclination in mandibular molars compared with maxillary molars (Figure 12-17). Considering these obstacles, control of the second molars should be a priority from the very beginning.

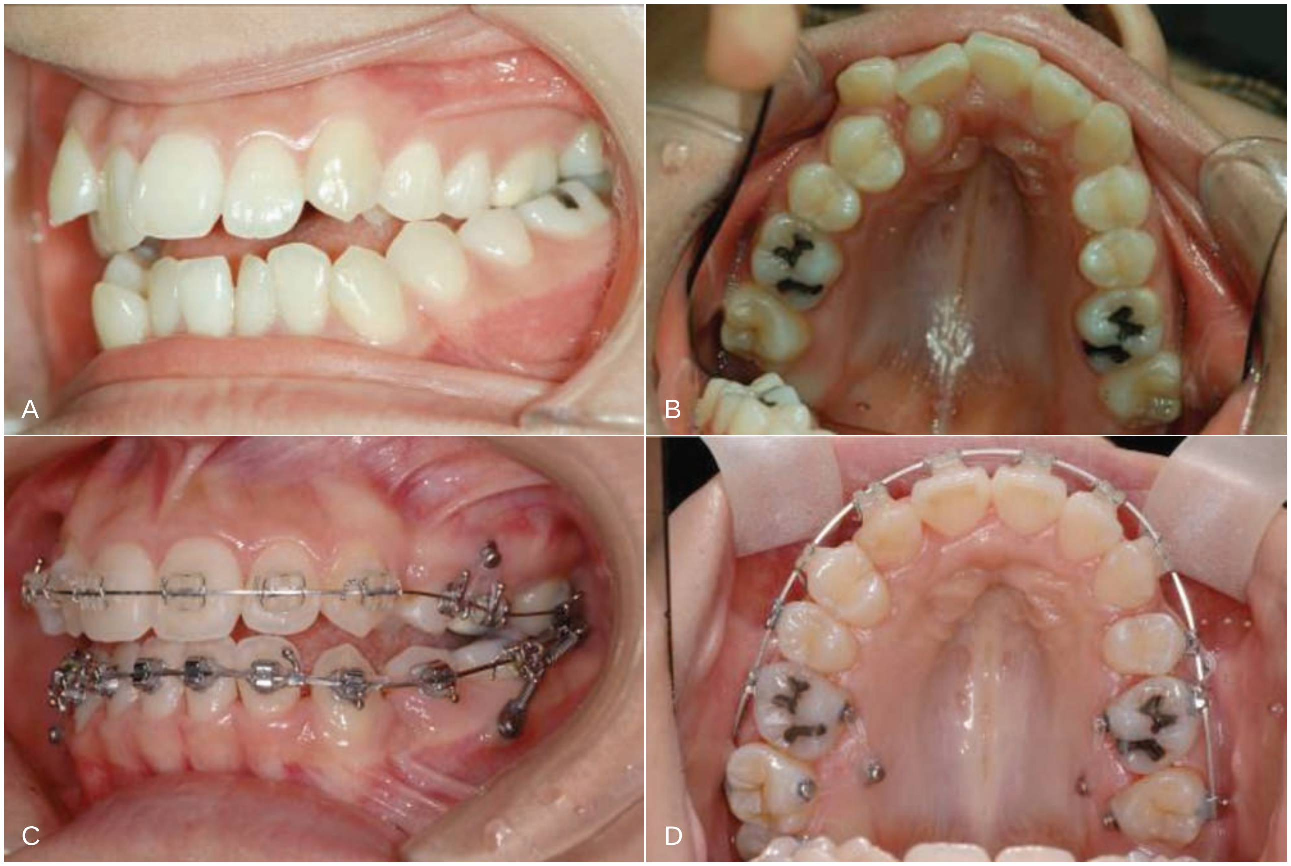

FIGURE 12-14 *Biomechanical efficiency of posterior intrusion:* As seen with anterior intrusion, use of a single force (i.e., force-driven mechanics) for posterior intrusion is effective and efficient as opposed to use of just the brackets and wires. Intrusion can also be achieved more quickly with a single force. A single force, however, is not effective for controlling arch form, tooth axis, inclination of the occlusal plane, and detailed adjustments. A continuous arch, which is a statically determinate force system, is advantageous for controlling the arch form, tooth axis, and individual tooth positions yet disadvantageous from the viewpoint of efficiency. If a combination of the two force systems is used, the disadvantages of each of the systems are mutually compensated. For maxillary molar intrusion, force-driven mechanics (i.e., single force) were used to increase efficiency on the palatal side, and shape-driven mechanics (archwire with compensating curve) were used on the labial side to adjust in detail. **A, B,** Intraoral views prior to treatment. **C, D,** Intraoral views after 3 months of molar intrusion with buccal and palatal TADs and a continuous archwire.

Molar Distalization

Decision-making. Three major factors should be considered when deciding whether to distalize a molar or not^{6}:

- *Required space:* If more than 3 mm of space per side is required to achieve the treatment objectives, premolar extraction may be preferable from the standpoint of treatment efficiency.
- *Hard tissue conditions:* There must be enough space for distalization. Second or third molar extraction should be considered before distalization to secure adequate space.
- *Soft tissue conditions:* A clinically acceptable amount of attached gingiva must be present following distalization, especially on the distobuccal aspect of the molar after mandibular molar distalization.

Biomechanics

Mechanical Efficiency. Distalization forces need to be efficiently applied to the molar itself as opposed to the other teeth. The distalization forces can be applied en masse or singly to each tooth.

In the maxilla, TADs placed on the palatal side can apply distalization forces directly to the molar. Moreover, these TADs can also control the mesiodistal axis of the molar through manipulation of the line of action (Figures 12-18 through 12-20).

Although adjacent teeth may limit mesiodistal tooth movement, buccal interdental mini-screw–type TADs are very useful in molar distalization because of ease of placement and simple application during treatment (Figures 12-21 through 12-23). With a properly positioned TAD, 3 mm of distal movement per side can be achieved.

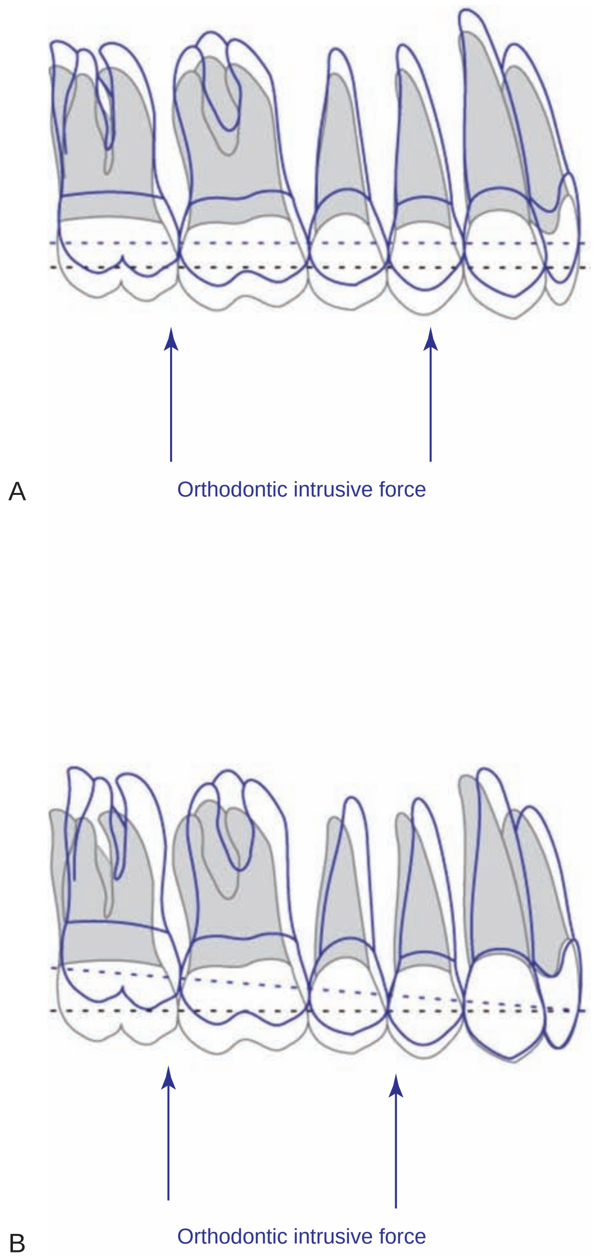

FIGURE 12-15 *Control from a lateral view:* Clinically, control of the inclination of the occlusal plane is one of the most important considerations in posterior intrusion and more specifically, the intrusion of the maxillary second molar is key. Occlusal plane inclination is related to molar axis control. **A,** To maintain the inclination of the occlusal plane, the premolars and anterior teeth should also be intruded approximately the same amount as the molars. This is especially indicated in the correction of a gummy smile or long face. **B,** The second molars should be intruded more than the premolars if the occlusal plane is to be steepened, especially in the correction of open bites. Steepening of the occlusal plane would be difficult to achieve. Note the change in the inclination of the posterior occlusal plane and the changes of the axes of the individual posterior teeth. This suggests that axis control is related to occlusal plane control. Furthermore, the individual posterior teeth should be tipped back to aid in steepening of the occlusal plane.

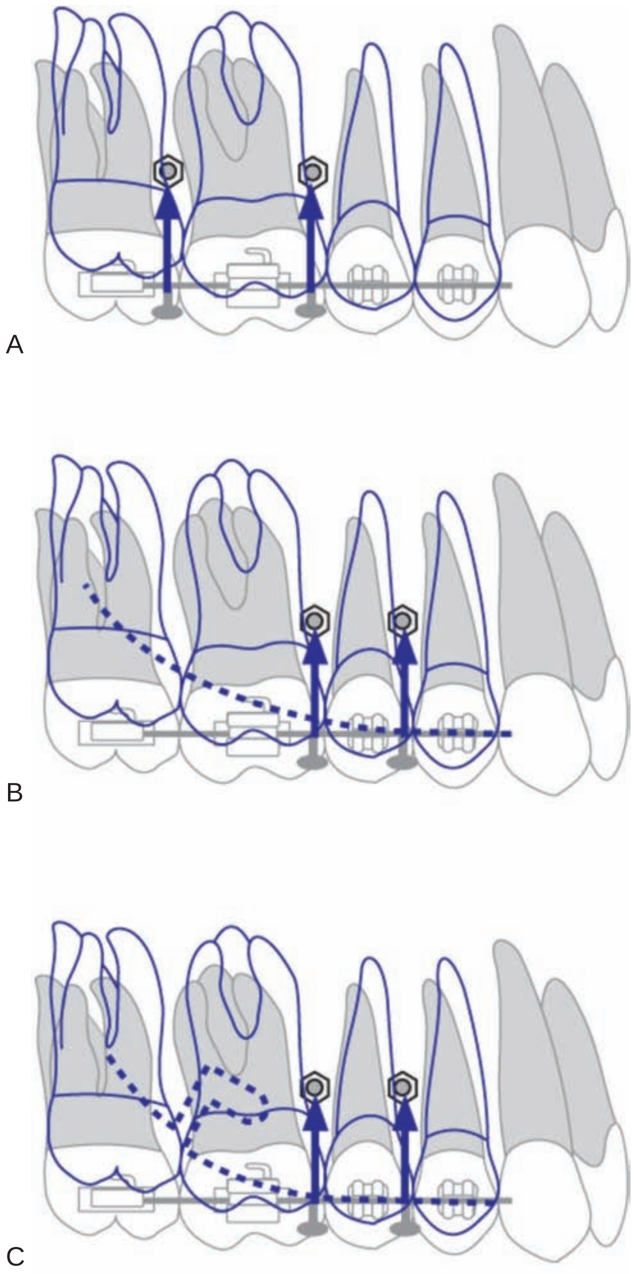

FIGURE 12-16 *Second-order control:* The single force generated from the TAD near the second molar is effective for the intrusion of the second molar **(A).** TADs may not always be positioned ideally, but the mechanical design can compensate for such limitations in placement. For example, tip back bends and/or step down bends **(B)** or L-loops **(C)** can be used to increase efficiency.

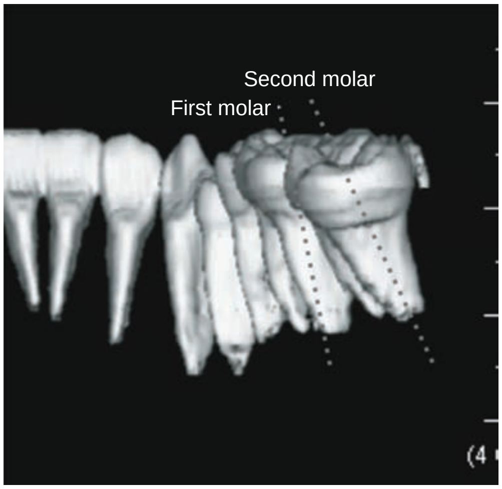

FIGURE 12-17 *Root inclination of the mandibular molar:* From a lingual view, three-dimensional CT reconstruction shows that the lingual inclination of the roots of the posterior teeth increases from the premolars to molars. In other words, the mandibular second molar is tipped more lingually than the mandibular first molar.

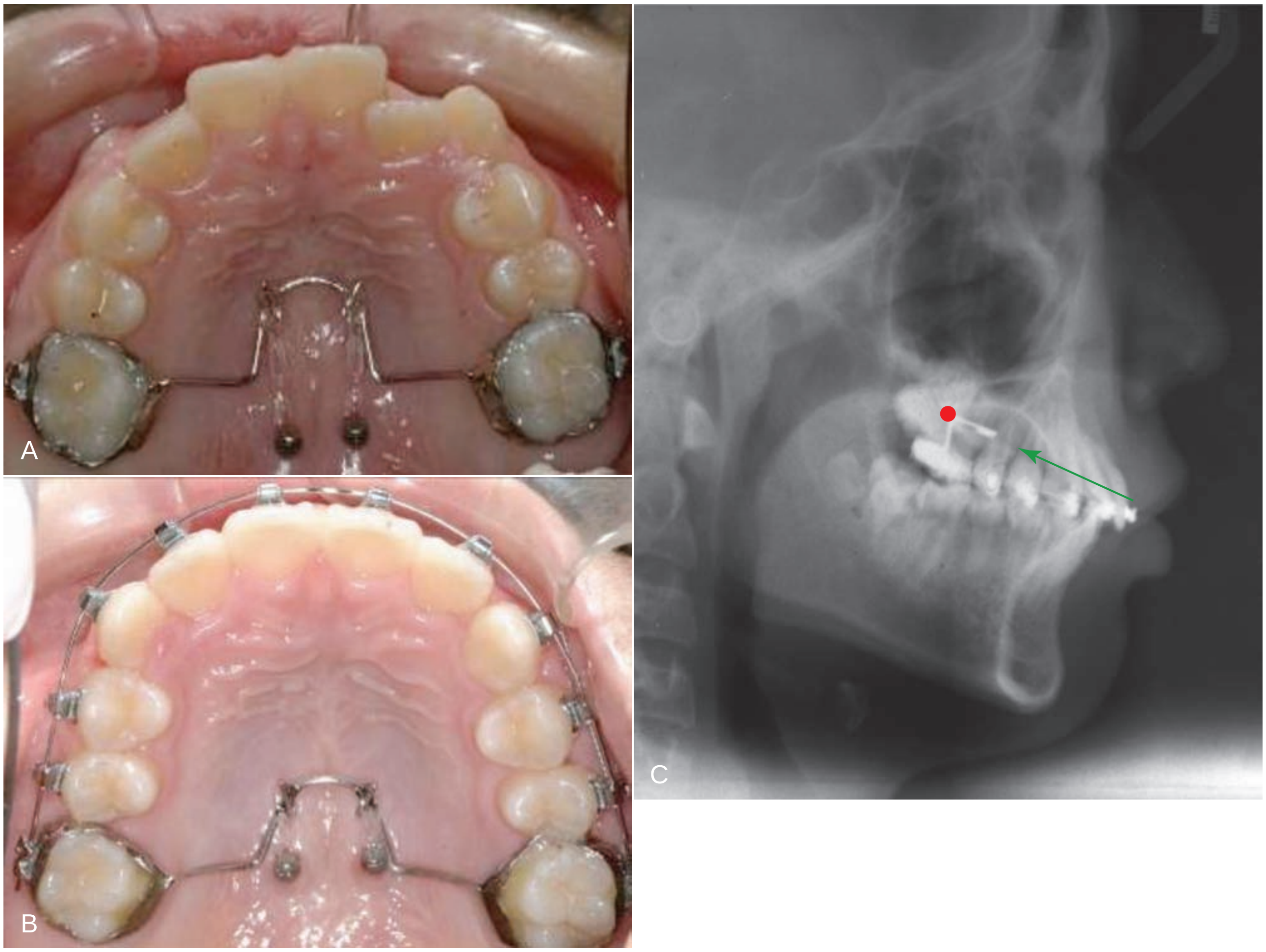

FIGURE 12-18 With a shallow palatal vault, mechanics that consist of TADs in the midpalatal suture area and a transpalatal arch are simple and effective. With this anatomical structure, distalization forces from TADs travel through the center of resistance of the molar, which produce distalization by bodily movement. In this clinical case, the patient was in a growing period. Thus, parasagittal TADs were placed, not the midsagittal TAD, because palatal suture growth was not completed. **A,** Intraoral view prior to treatment. **B,** Intraoral view during treatment. **C,** Cephalometric radiograph during molar distalization. Distalization force (*green arrow*) is through the center of resistance of the molar (*red dot*).

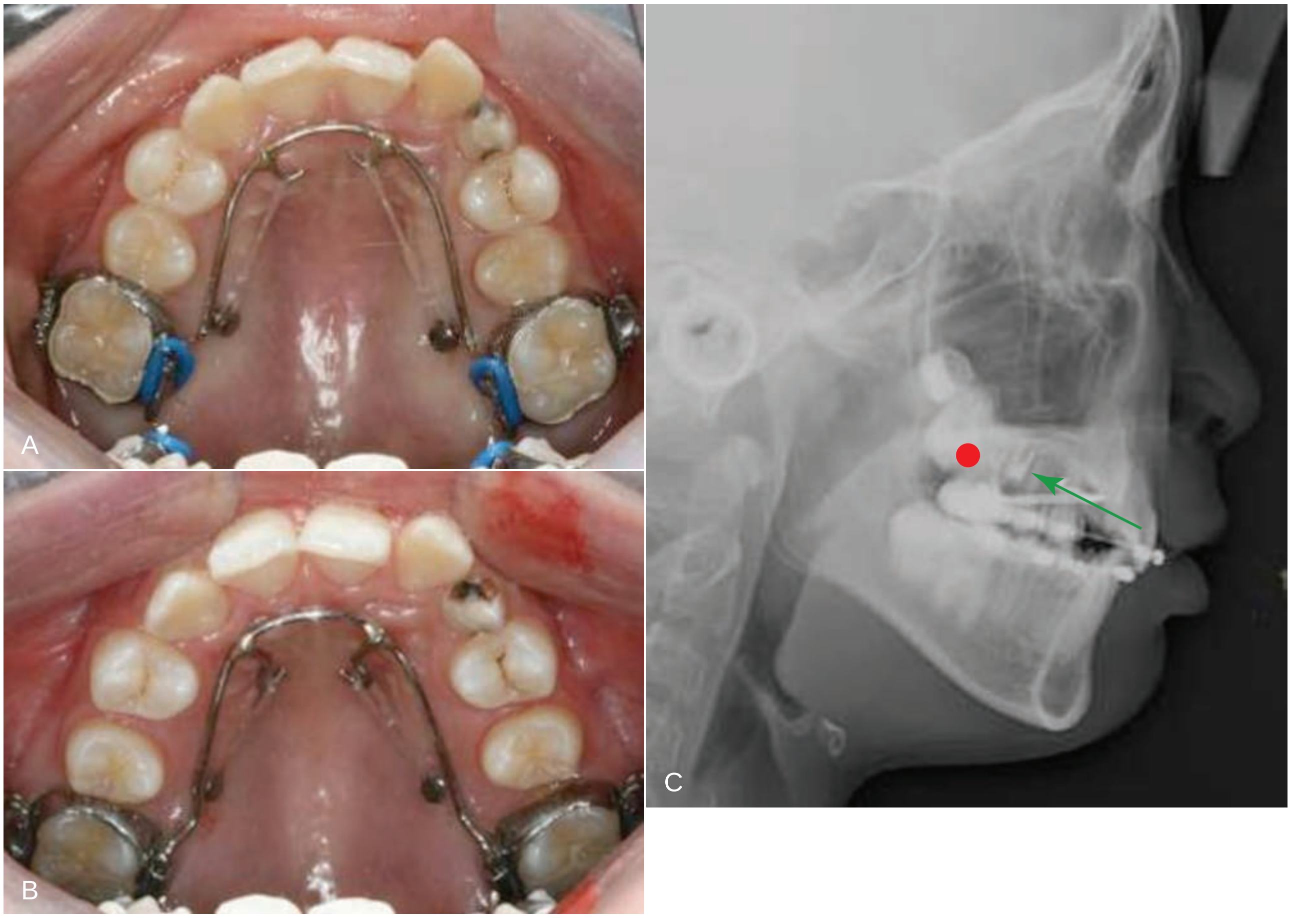

FIGURE 12-19 By modulating the line of action, distalization by bodily movement can be produced. With deep palatal vaults, TADs in the palatal interdental area and a transpalatal arch can produce distalization forces that travel through the center of resistance of the molars (*red dot*). **A,** Intraoral view prior to molar distalization. **B,** Intraoral view after 5 months of molar distalization. **C,** Cephalometric radiograph during molar distalization. Distalization force (*green arrow*) is through the center of resistance of the molar (*red dot*). The line of action is moved occlusally by TAD positioning when compared with the case in Figure 12-18.

Three-dimensional Control. As with molar intrusion, three-dimensional control of the molar is important in molar distalization using TAD mechanics (Figures 12-24 through 12-29). Thus, the mechanics should be designed to manage the three-dimensional position of the molar. Once again, there are several ways to achieve this control: the use of a single force from the TAD, the use of brackets and archwires, and the combination of both systems.

En Masse Distalization. All of the anterior and posterior teeth can be distalized at the same time using rigid anchorage. The same principles are applied for full dentition distalization as for single tooth movement. Considerations for mechanical efficiency and three-dimensional control are necessary as well. With regard to three-dimensional control, the center of resistance of the total dentition can be estimated.[97] Theoretically, if the force is applied through the center of resistance of the whole dentition, translation of the entire dentition will be achieved. Clinically, however, there is a greater tendency for the teeth to move individually as opposed to entirely (Figure 12-30). Furthermore, if the dentition moves as a whole body and does not allow for tipping of individual teeth, movement will be very slow. Even in en masse distalization, the key point is molar control. If the molars are well controlled three-dimensionally, moving the remaining teeth is comparatively easy. En masse movement is indicated when intrusion is needed in addition to distalization.

Molar Protraction

Decision-making. TADs can provide stable anchorage for molar protraction.[98–101] However, molar protraction toward an edentulous area can be affected more by biological conditions than by biomechanics.[102–104]

When the first molar or second premolar is missing, protraction in the maxilla is somewhat predictable. But in the mandible, there are various individual differences.

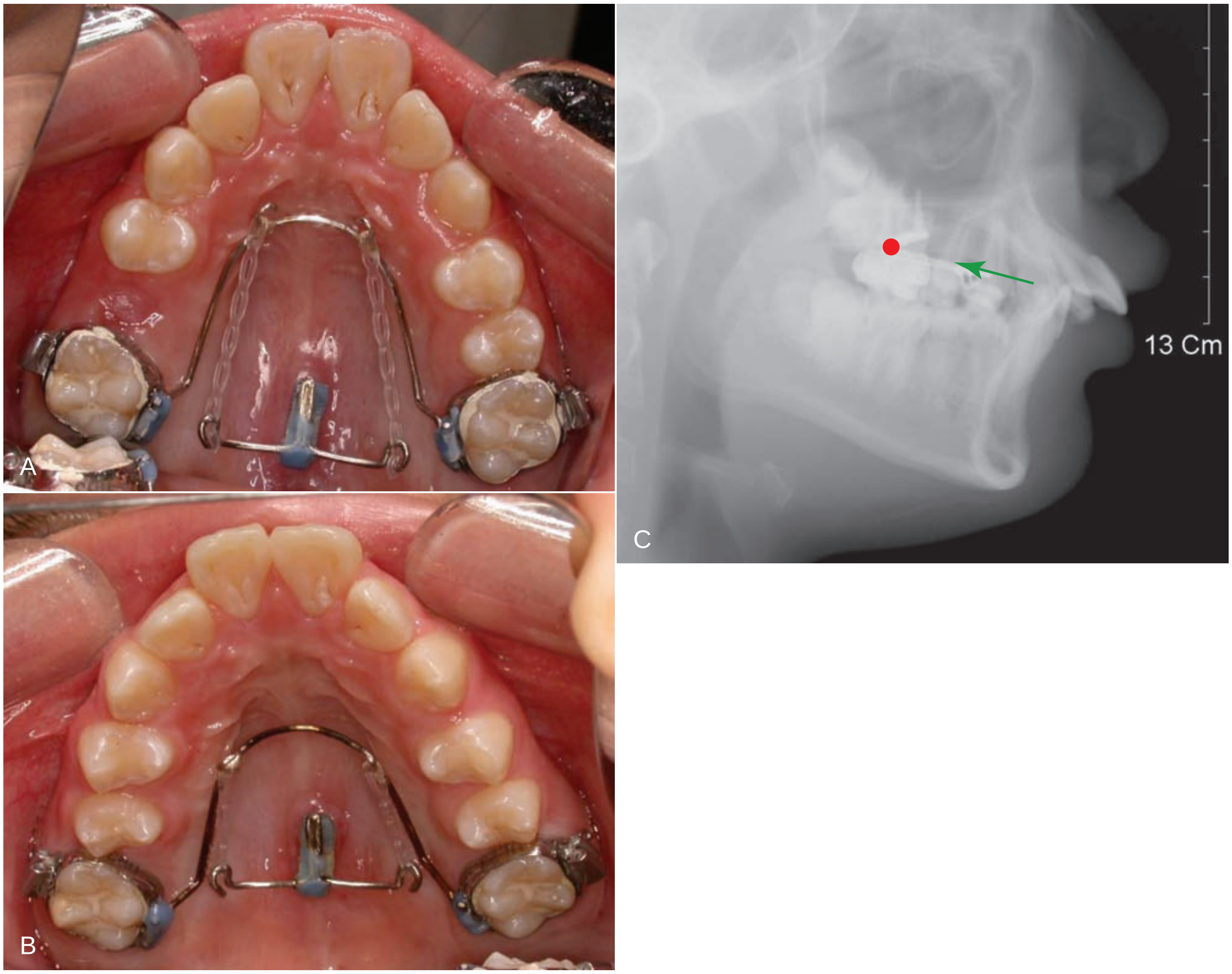

FIGURE 12-20 With deep palatal vaults, TADs in the midpalatal suture area and an attachment on them can modulate the line of action to produce distalization forces (**C,** *green arrow*), which travel through the center of resistance of the molars (**C,** *red dot*). If the distalization force is coming directly from the midpalatal TADs, as in this clinical case, the line of action passes more apically (**C,** *black arrow*) than the center of resistance of the molar. **A,** Intraoral view prior to distalization. **B,** Intraoral view during molar distalization. **C,** Cephalometric radiograph during molar distalization.

According to research conducted by Roberts et al.,[100] the rate of molar traction can be as low as 0.2 mm per month. Extra caution should also be taken when moving teeth into edentulous areas in the mandible because severe periodontal attachment loss can be induced during protraction depending on the condition of the alveolar bone.[103,104]

Therefore, the following precautions should be considered when protraction into an edentulous area is planned, especially in the mandible, to prevent loss of attachment. It is necessary to evaluate the periodontal condition of the area where protraction is planned. Vertical and transverse bone quantity influences the periodontal prognosis. Low alveolar bone levels and narrow alveolar bone have a higher chance of attachment loss. An inadequate amount of attached gingiva has a higher chance of attachment loss as well. The patient's chronologic and dental ages should be also considered because growing children and patients with incomplete third molar development have a lower chance of attachment loss.

Biomechanics. Three-dimensional control is also important for successful protraction (Figures 12-31 through 12-33).

Anterior Retraction in Extraction Treatment

A unique feature of TAD mechanics in premolar extraction cases is the ability to adjust the anteroposterior position of the anterior teeth and molars. Moreover, TAD mechanics can correct vertical

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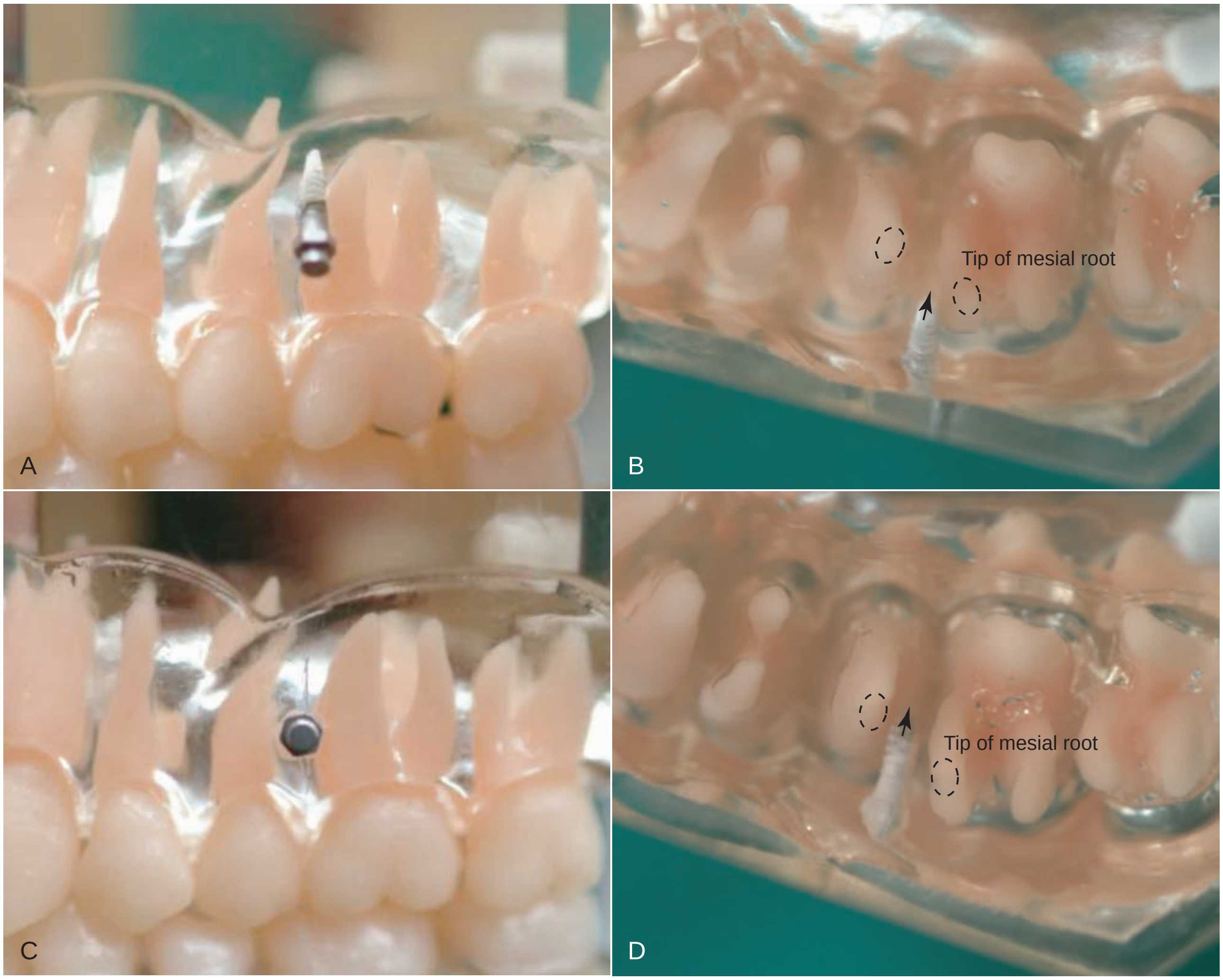


FIGURE 12-21 Buccal alveolar bone can provide enough space for a half-cusp width of distalization if the TAD is properly placed. However, narrow interradicular widths cannot provide enough space for mesiodistal movement. Angular placement of the TAD to the occlusal plane **(A, B),** as opposed to parallel to the occlusal plane **(C, D),** can take advantage of a wider buccal space.

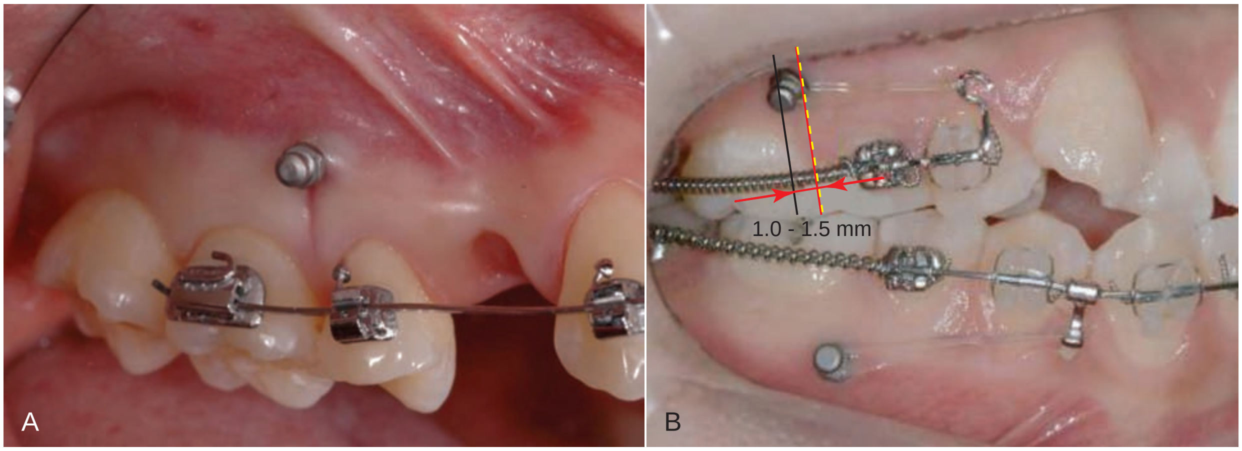


FIGURE 12-22 Off-center placement of the TAD to the distal is also important in molar distalization. However, the protocol for the prevention of root injury should be followed in order to minimize the possibility of root injury. Normal insertion site on buccal alveolus: The orthodontic mini-implant is usually placed on the midline between the adjacent teeth and at the connecting point of mucogingival junction (MGJ) **(A).** The TAD is placed 1.0 to 1.5 mm distal from the midline (yellow line) because molar distalization is planned **(B).**

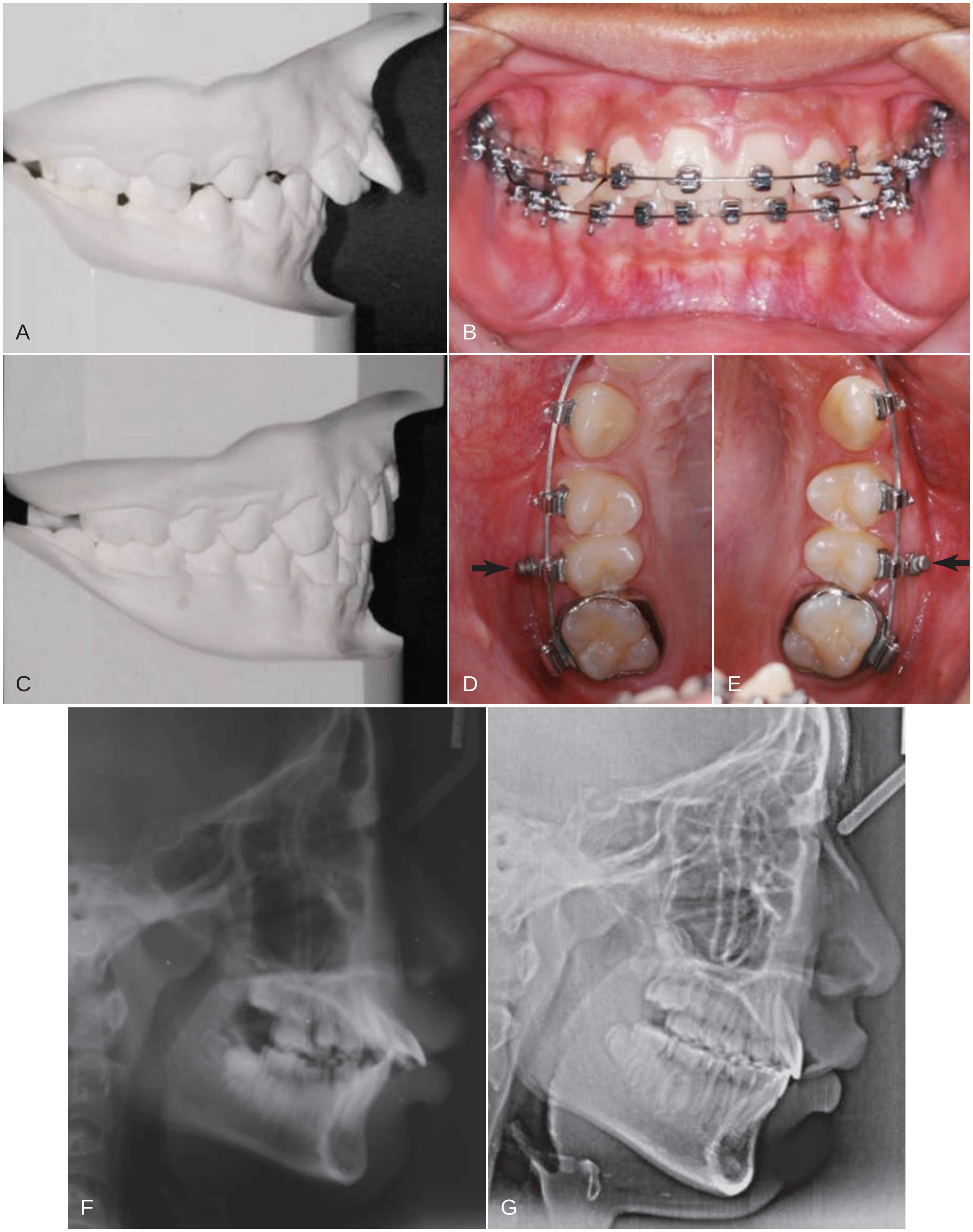


FIGURE 12-23 The patient was a 12-year-old boy whose chief complaint was protrusion. Severe overjet and Class II canine and molar relationship were corrected by molar distalization using TADs placed in the buccal interdental area. Initial positions of the TADs at the beginning of treatment were close to the first molars. But, after distalization, the TADs seemed to be on the same line as the root of the second premolar **(D, E).** If placed with proper angulation in order to make use of the buccal space and placed closer to the distal portion rather than in the middle of the interproximal space, buccal implants are also useful in molar distalization. **A,** Occlusal relationship prior to treatment. **B,** Intraoral view during molar distalization. **C,** Occlusal relationship at the completion of active treatment. **D, E,** Intraoral view during treatment. Buccal TADs were on the same line as the second premolar (*black arrows*). **F,** Cephalometric radiograph prior to treatment. **G,** Cephalometric radiograph at the completion of active treatment.

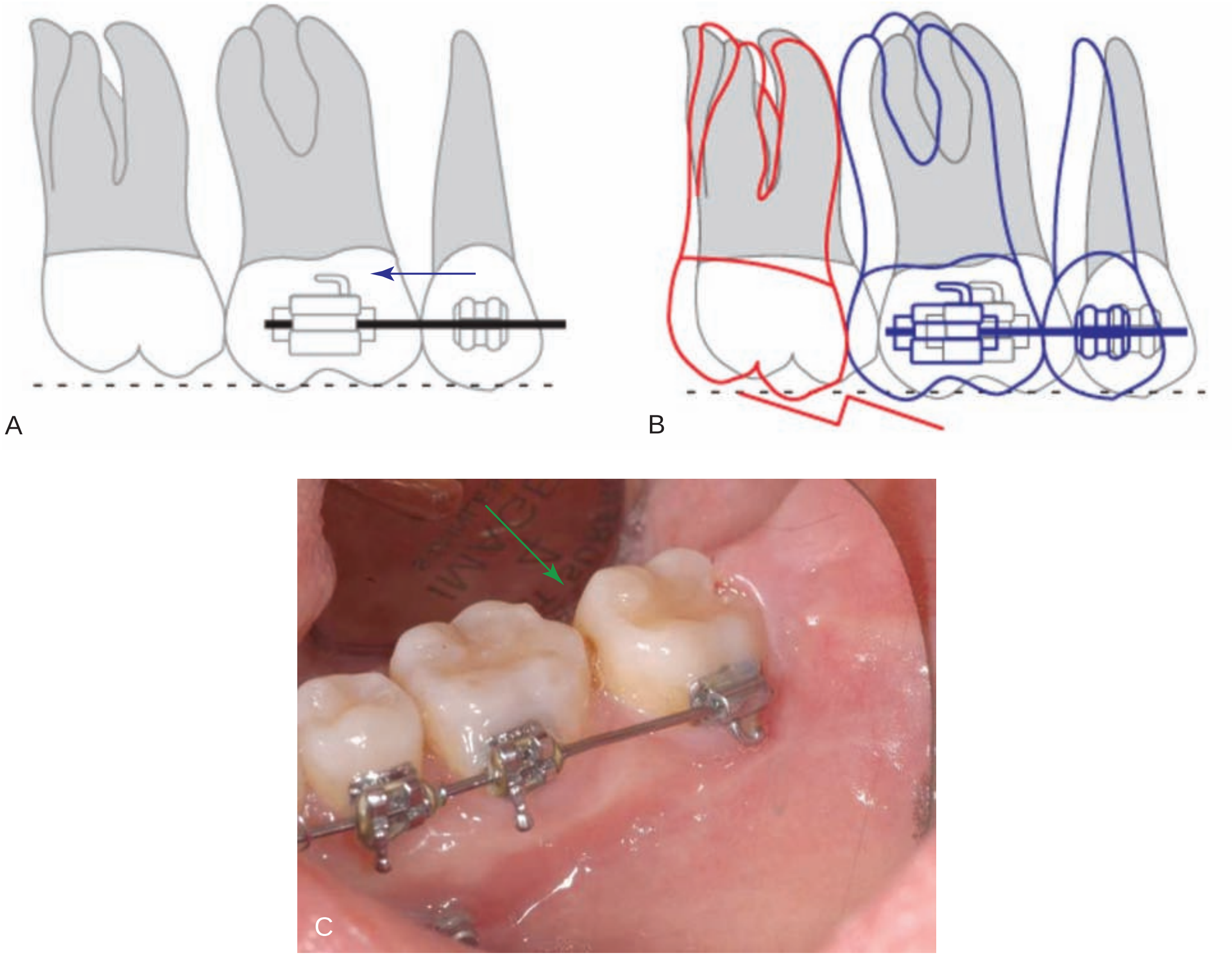


FIGURE 12-24 *Mesiodistal axis control:* **A, B,** If the second molar is not included, it may tip back due to distal movement of the first molar and marginal ridge discrepancies can be created. The second molar should be controlled simultaneously whenever possible during molar distalization to prevent any vertical discrepancies. **C,** Even with strap-up including the second molar, bodily distalization of the second molar is not easy to attain because tipping can occur easily. A clinical sign of tipping is second molar mesial marginal ridge elevation (*green arrow*). To prevent distal tipping while distalizing, the use of wires of adequate stiffness is also a practical consideration.

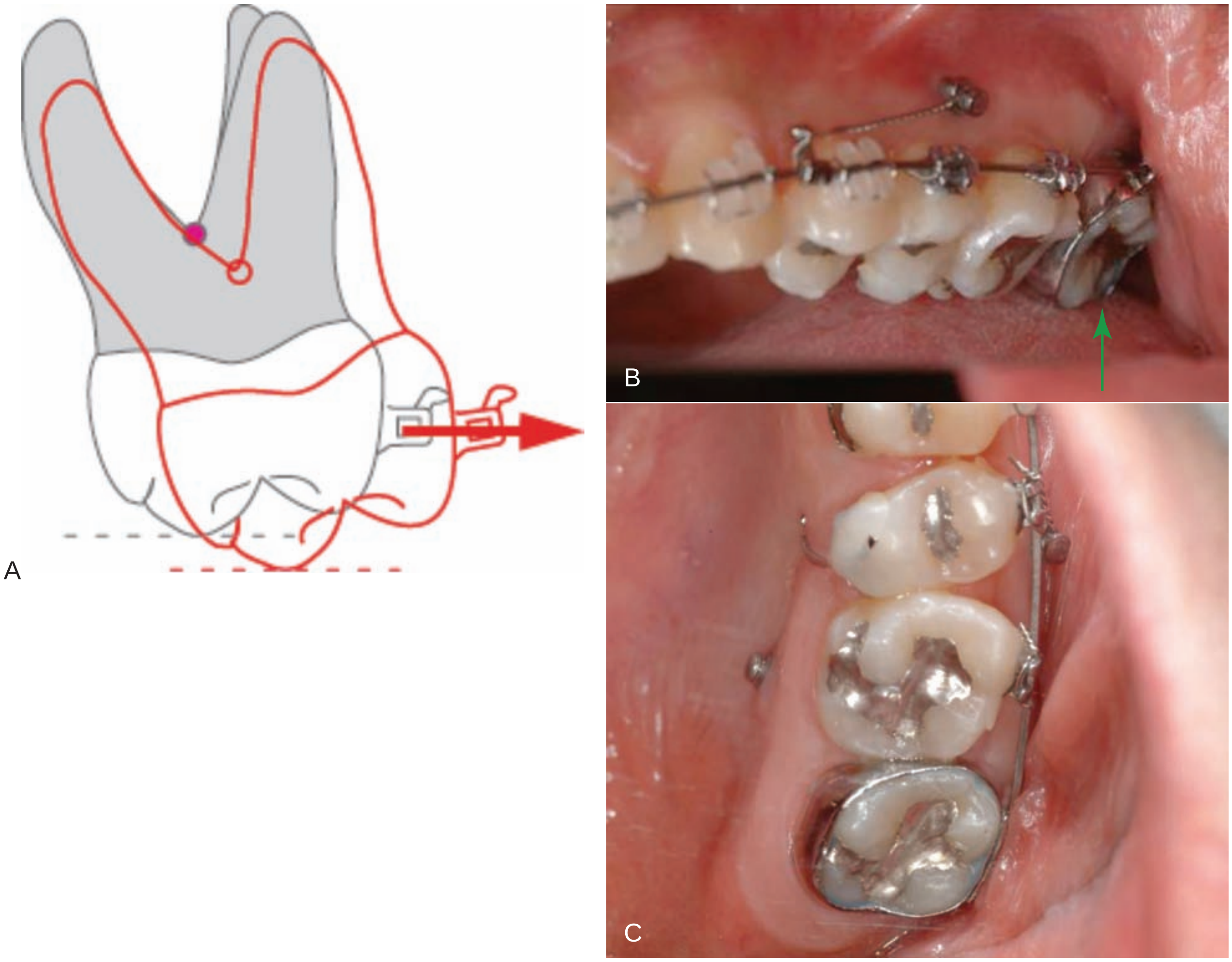


FIGURE 12-25 *Arch form (buccolingual positioning) and torque control:* During distalization, the maxillary second molar can be easily tipped buccally, while the mandibular second molar can be easily tipped lingually, due to the respective buccolingual inclinations of these molars. In addition, posterior torque control and arch form (buccolingual positioning) control are related. If the second molar is tipped to the buccal, the palatal cusps fall inferiorly and the torque of the second molar worsens. A slight toe-in bend may aid in controlling the buccolingual positioning of the second molar and, as a result, also be useful in controlling torque. **A,** Schematic illustration of arch form changes and the relationship between buccolingual position and torque. **B,** Intraoral view after molar distalization. The second molar torque worsened because of buccal tipping (*green arrow*).

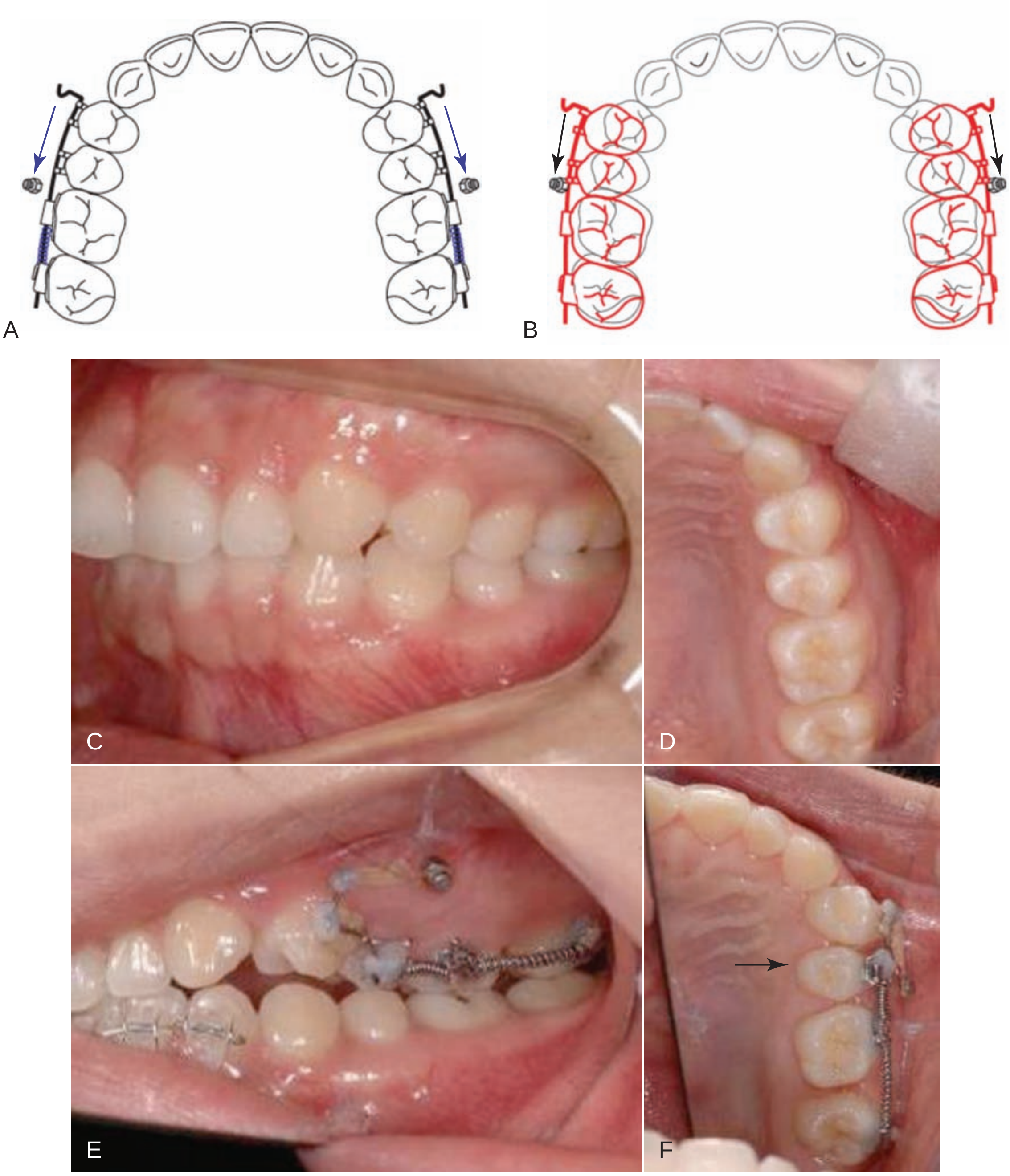
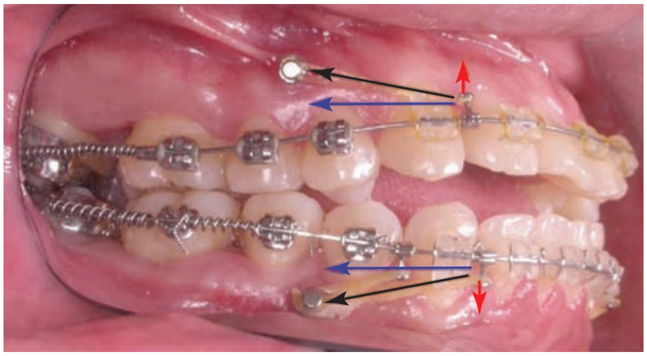


FIGURE 12-26 *Arch form control:* Sectional mechanics without cross-arch splinting is not adequate for arch form control because of the tendency for mesial-out rotation of the posterior segment. **A, B,** Schematic illustrations of rotation of the buccal segment by distalizing forces. **C, D,** Intraoral views before molar distalization. **E, F,** Intraoral views during molar distalization. Notice the mesial-out rotation (*black arrow*).

FIGURE 12-27 *Vertical control:* Distalization forces may have intrusive force vectors because of geometric positions of the TADs. Intrusive force vectors, in turn, may cause unwanted intrusion such as anterior bite-opening or occlusal plane canting, which are difficult to correct once developed. Therefore, such intrusive force vectors should be controlled. The use of lever arms is one way to effectively eliminate intrusive force vectors (*black arrow*, retraction force; *purple arrow*, distalizing force vector; *red arrow*, intrusive force vector).



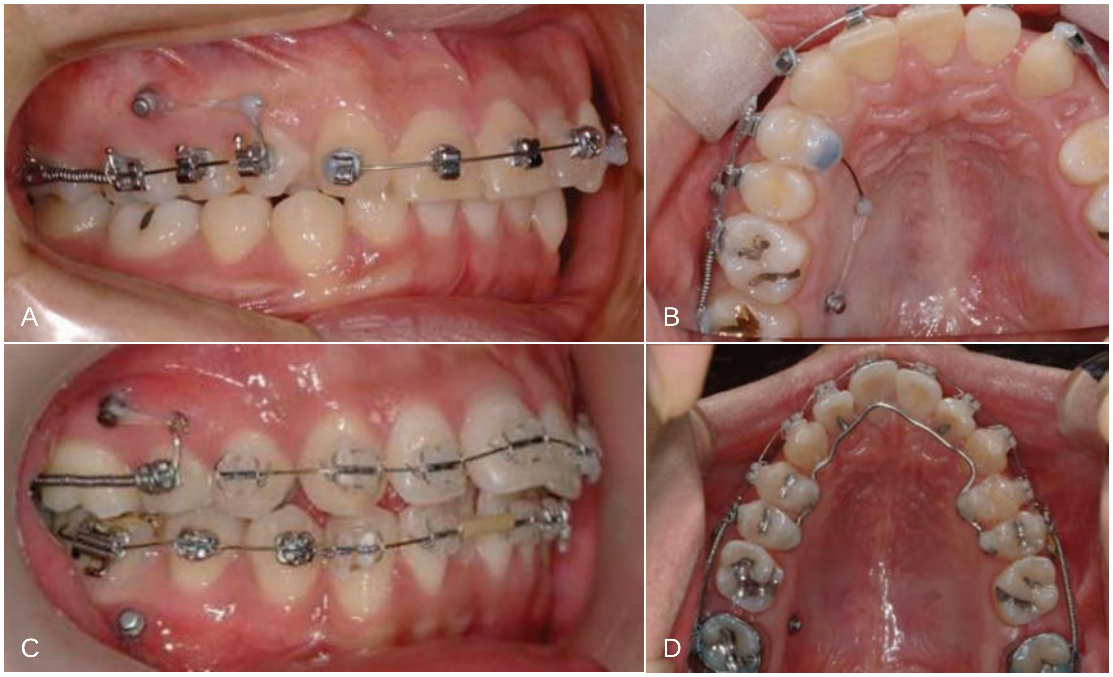


FIGURE 12-28 *Arch form and vertical control:* **A, B,** Lever arms are used for vertical control. Applying buccal and palatal distalizing force simultaneously is also effective for arch form control and useful for asymmetric distalization. **C, D,** Lever arms were used for vertical control **(C)** and cross-arch splinting for arch form control **(D).**

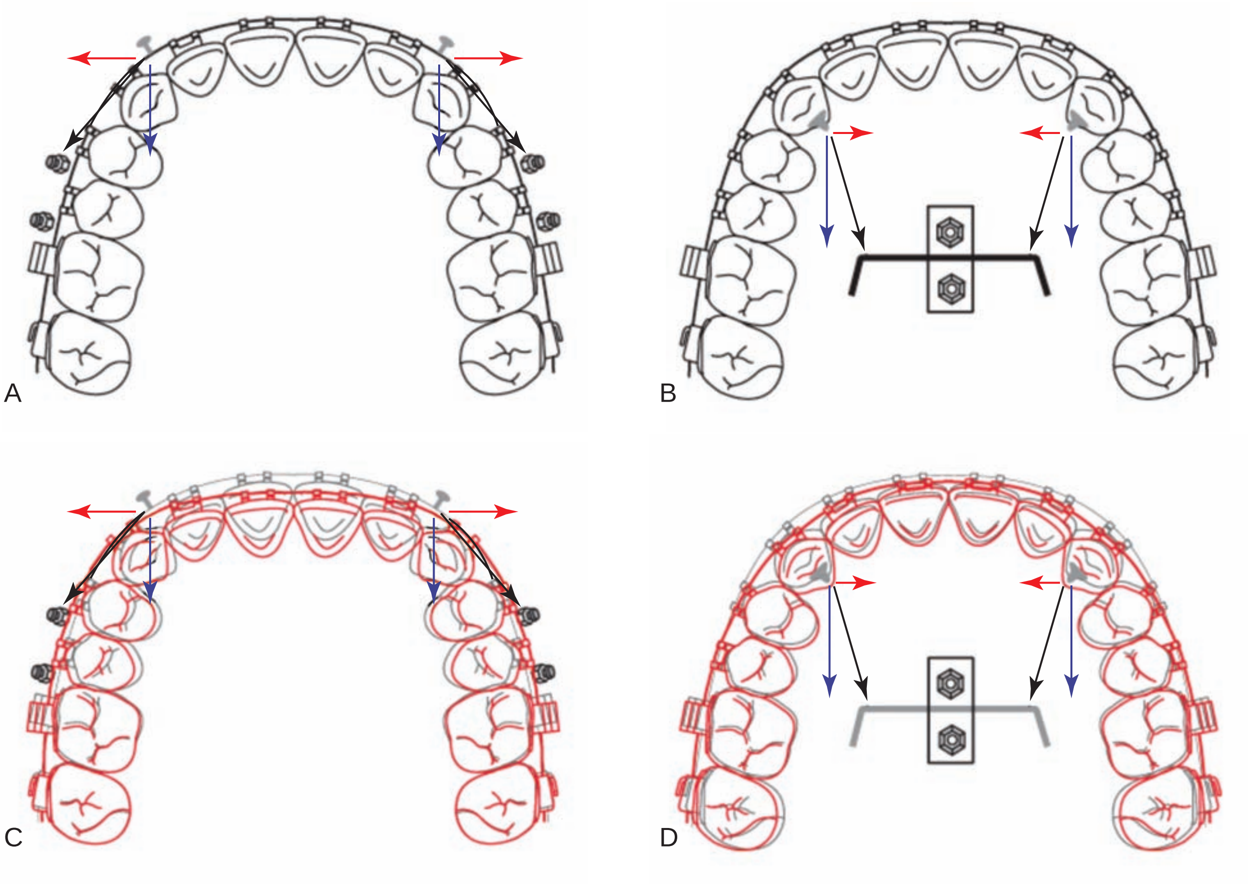


FIGURE 12-29 According to geometric positions of the TADs, distalizing forces have a horizontal force vector. In addition to distal movement, buccolingual tipping is more likely to occur than distal movement because the sum of the circumcemental area of the molar roots is greater than the sum of the anterior teeth. These horizontal force vectors may develop arch expansion **(A, B)** or constriction **(C, D).**

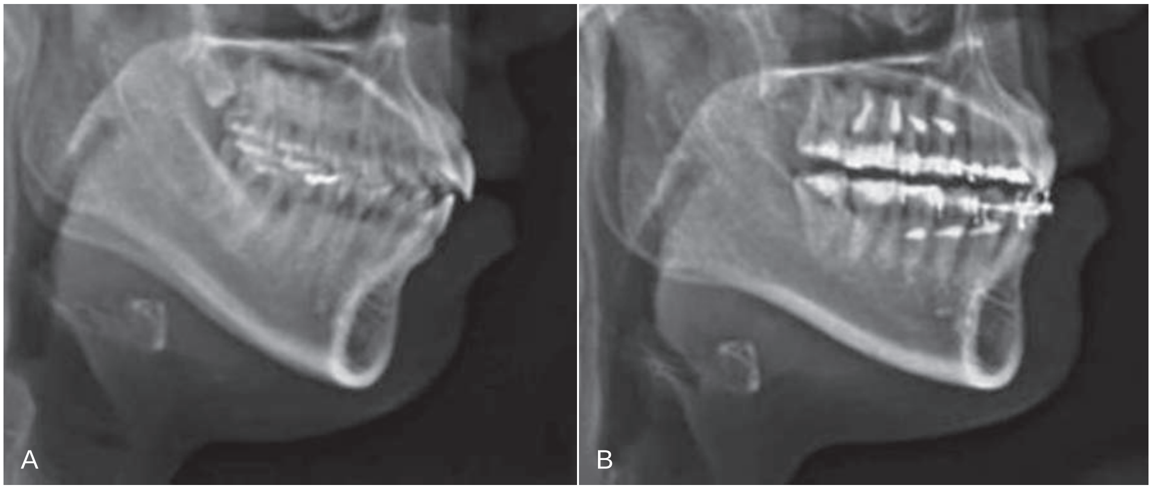


FIGURE 12-30 The entire dentition was distalized to correct protrusion. Even though twin brackets were used, distal tip back of the individual teeth was observed. **A,** Cephalometric radiograph prior to treatment. **B,** Cephalometric radiograph after molar distalization.

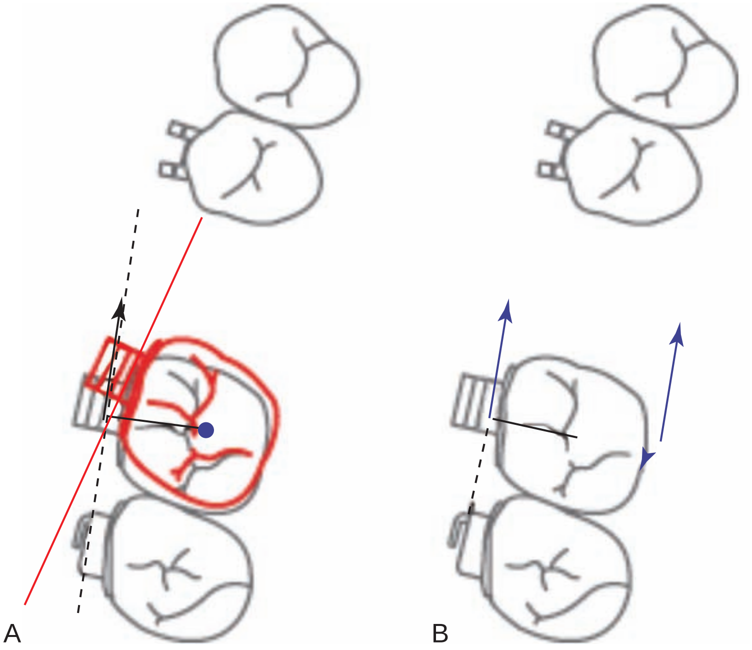


FIGURE 12-31 *Rotation control:* Buccal protraction forces produce a moment of mesial-in rotation **(A).** Adding lingual protraction force **(B)** is a simple and effective way to offset this mesial-in rotation tendency.

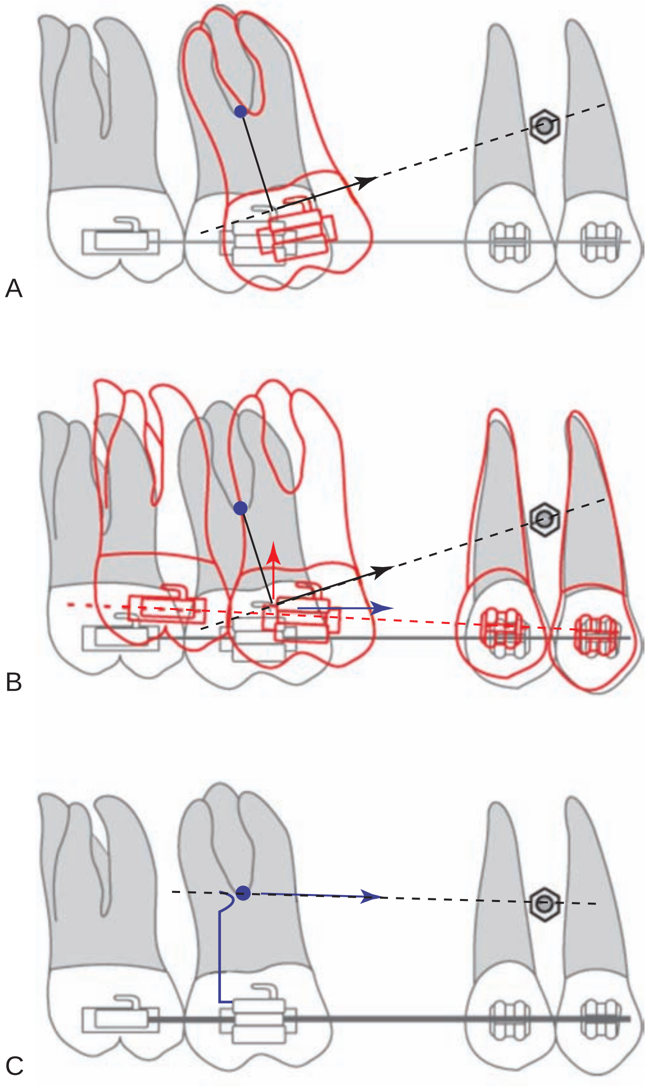


FIGURE 12-32 *Molar axis and vertical control from a lateral view:* **A,** Protraction forces away from the center of resistance cause an inclination for mesial tipping. **B,** Generally, TADs are placed apically, and as a result, protraction forces have intrusive force vectors. If intrusion occurs on only one side, occlusal canting can develop and this is very difficult to correct if it occurs. **C,** A lever arm engaged in an auxiliary tube on the first molar is effective in vertical control.

disharmony simultaneously during anterior retraction[10,13,16,17,105] (see Figure 12-4).

Decision-making. First, adequate alveolar space is necessary for bodily retraction of the roots of the anterior teeth. Verification of the amount of alveolar bone is necessary during treatment planning procedures. When a large amount of retraction is planned, there is higher risk for root resorption and periodontal attachment loss[52]; therefore, risk management is important. Also, precaution is greatly needed to avoid overretraction and overintrusion of the anterior teeth when using rigid anchorage.

Biomechanics. Biomechanically speaking, there is no significant difference between conventional mechanics and TAD mechanics with regard to anterior retraction. The general principles in extraction treatment with conventional edgewise techniques are also important in extraction treatment with mini-implants. The proper force system should be designed, and monitoring this system is especially important, as it is with conventional mechanics.

The TAD can supply rigid anchorage for maximum anterior retraction and anterior torque adjustment. Moreover, TADs are generally placed apically, making it advantageous to control the line of action for canine axis and torque control during retraction (Figure 12-34).

To achieve successful anterior retraction, canine axis control and anterior torque control are imperative, even with TAD mechanics. Canine lingual tipping, which is loss of canine torque, should be closely followed in cases with large amounts of anterior retraction (Figure 12-35).

When the retraction force is generated directly and only from the TAD, some considerations are needed[13,16,17,105] (Figures 12-36 and 12-37). Canine control becomes more critical. Additionally, the intrusive force vector of TAD mechanics is available for vertical control of the anterior teeth, but when left improperly monitored, side effects such as occlusal plane canting can occur.

One should remember that the TAD itself is not controlling the canine axis and anterior torque.

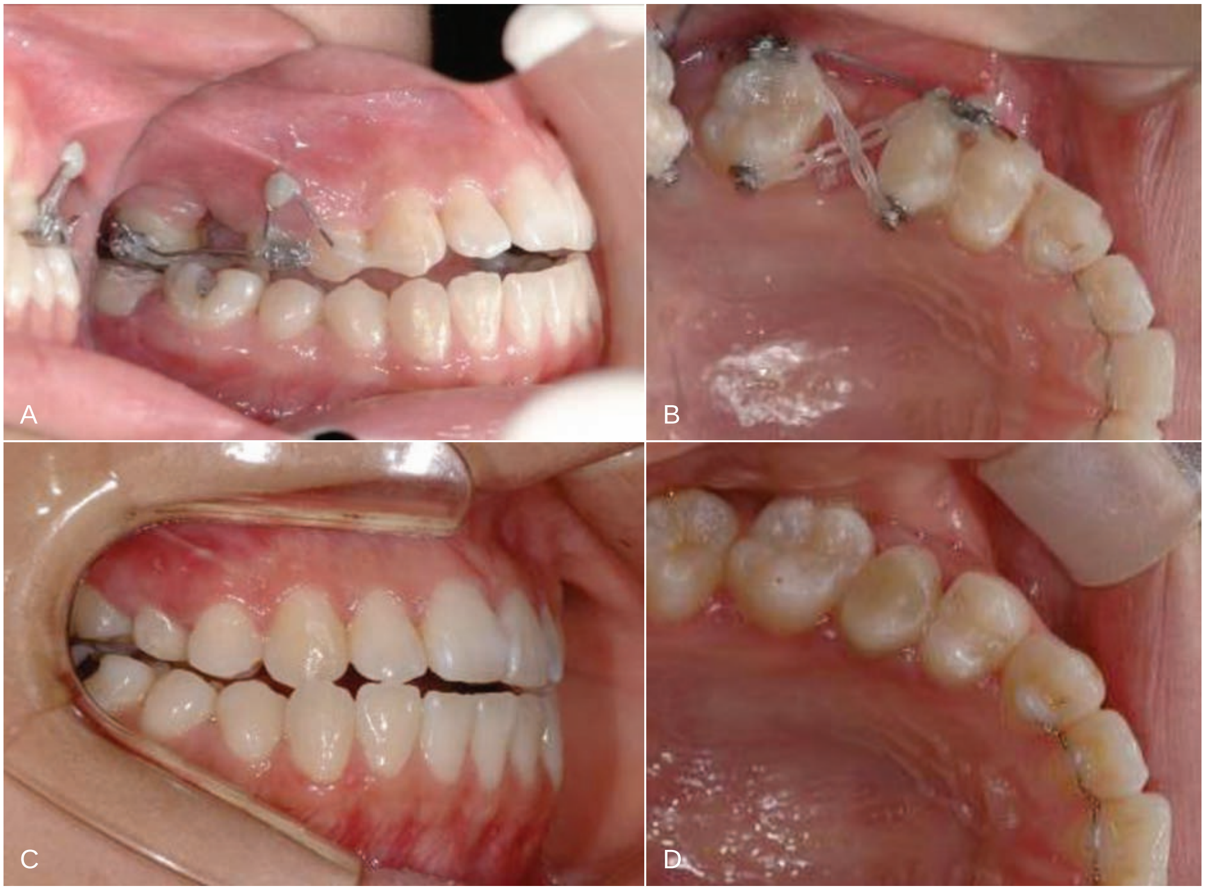


FIGURE 12-33 The patient was an 18-year-old girl, whose problem was the severely mutilated upper fist molar. Because of prolonged inflammation, there was little alveolar bone left in the upper fist molar area. Using TADs, the second molar was protracted after extraction of the first molar and the third molar erupted to the proper position. The periodontal tissue of the protracted second molar was in good condition. Indirect application is also effective in vertical control, and this same application can also provide stable anchorage in cases of unilateral molar protraction. **A, B,** Intraoral view at the start of treatment. **C, D,** Intraoral view at the completion of treatment.

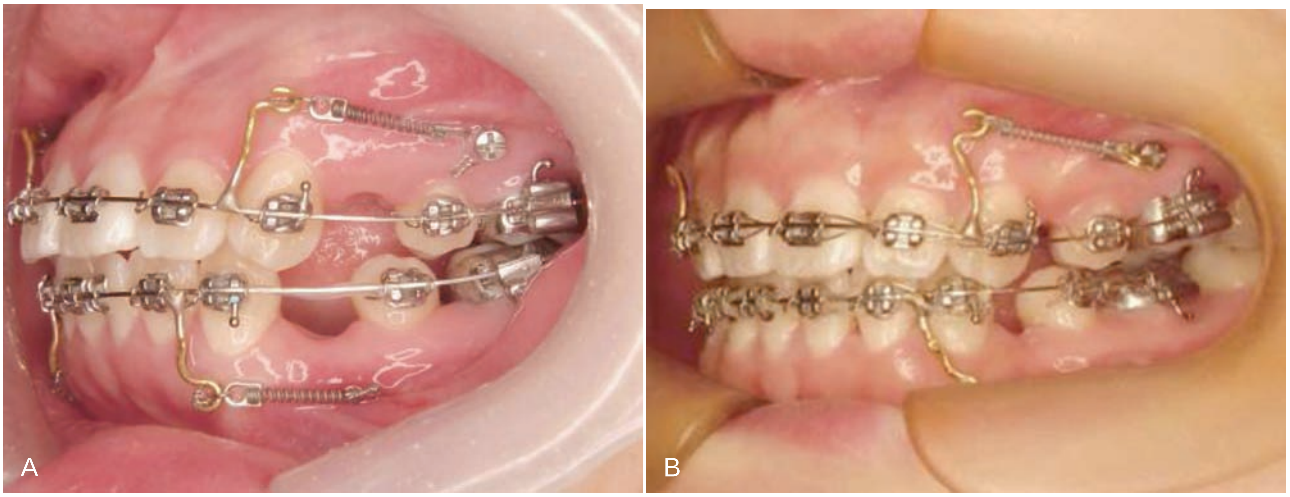


FIGURE 12-34 The line of action can be moved apically by using long lever arms for anterior torque control during retraction. **A,** Intraoral view at the start of the anterior retraction. **B,** Intraoral view during anterior retraction.

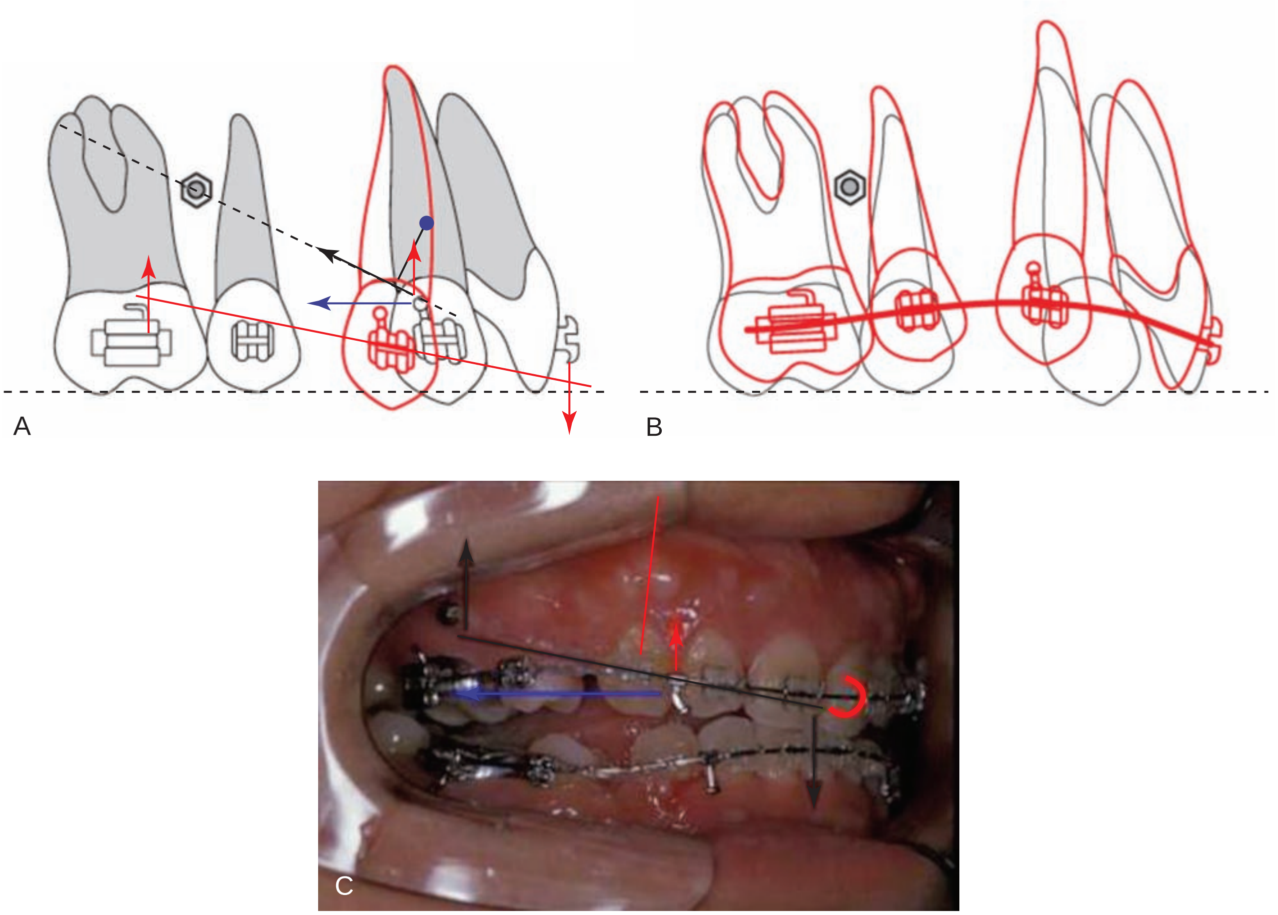


FIGURE 12-35 Distal tipping of the canine causes deflection of the archwire **(A).** As a consequence, extrusion force develops in the anterior teeth and it worsens anterior torque. Moreover, by the deflection (twisting) of the archwire, lingual crown torque has been produced in the anterior teeth and this induces loss of anterior torque. The posterior segments are intruded by deflection of the main archwire caused by distal tipping of the canine and the intrusive force vector from retraction force **(B, C).**

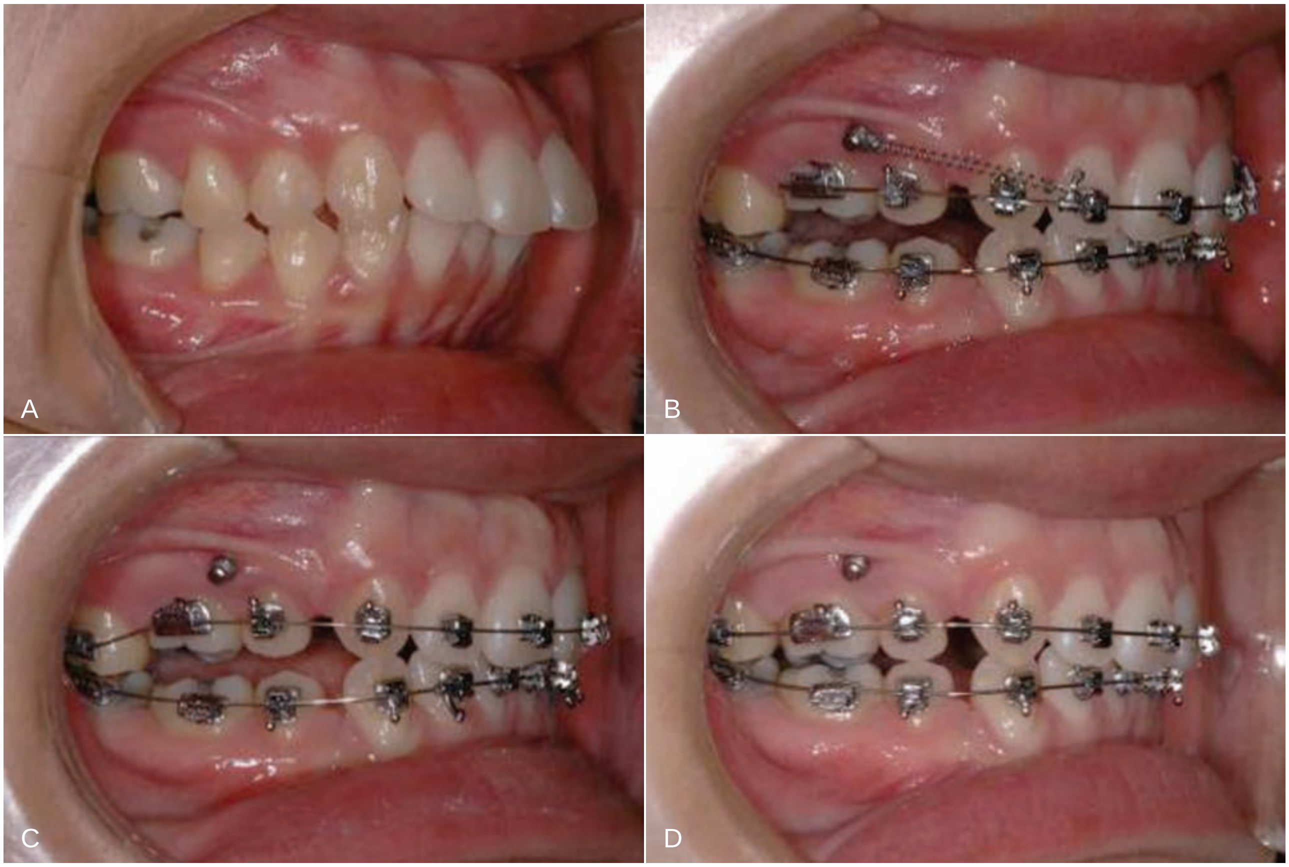
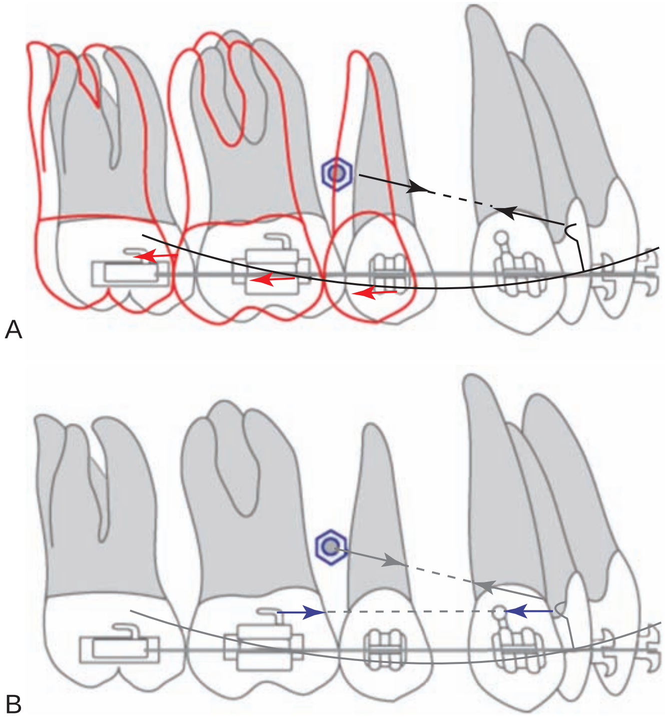


FIGURE 12-36 Canine axis control and control of the intrusive force vector are important in preventing posterior bite opening. A posterior bite opening was corrected by canine axis control and wire engagement into the second molar. **A,** Intraoral view prior to treatment. **B,** Intraoral view during anterior retraction. Posterior bite opening was noted. **C,** An attachment was bonded to the second molar. A leveling archwire was placed, and the retraction force was removed. **D,** Intraoral view during anterior retraction. Posterior bite opening improved.

FIGURE 12-37 When a TAD is used for anterior retraction, particularly with a curved main archwire, the retraction force can be delivered to the posterior teeth by friction of the archwire. As a consequence, the posterior teeth can be distalized **(A).** This distal movement of the posterior teeth can be monitored by checking the intermaxillary occlusal relationship. Application of a light force to the molar is useful in maintaining molar position **(B).**



CASE STUDY 12-1

NONSURGICAL CORRECTION OF VERTICAL EXCESS

Retraction and Intrusion of Maxillary and Mandibular Dentition

Jong Suk Lee

The patient was a 28-year-old woman whose chief complaint was protrusion of the lips, even after orthodontic treatment with three premolar extractions. She exhibited an acceptable occlusion and a nice posed smile but had the typical features of a long-faced patient: a long lower third of the face, lip incompetence, extreme mentalis strain upon lip closure, and a recessive chin. Cephalometric analysis confirmed anterior vertical excess with a flat occlusal plane. Surgical correction may have been an option, but the patient desired a nonsurgical approach. Therefore, maxillary and mandibular molar intrusion and distalization with orthodontic mini-implants were planned to correct the protrusion and vertical excess and to improve the facial aesthetics.

In an effort to distalize and intrude the entire dentition, continuous arch mechanics were used. To provide the proper space for the lower dentition, lower third molars were extracted. The mechanics consisted of buccal mini-implants (Orlus mini-implants, 1.8 mm in diameter and 7.0 mm in length in the maxilla, 1.6 mm in diameter and 7.0 mm in length in the mandible) and 0.017 × 0.025-inch TMA wire (Ormco) with a tip back bend to intrude the molars and control occlusal plane inclination. A constriction bend was also applied to control arch form (Figure 12-38, *G–I*). Palatal or lingual TADs were not used.

Active treatment to the desired position was completed after 20 months. The entire dentition was distalized and intruded with only the use of buccal mini-implants. The cephalometric superimposition shows that the upper and lower anteriors were retracted and that the chin point moved upward and forward (Figure 12-38, *W*).

Fixed retainers extending from first premolar to first premolar were used in the maxilla and mandible. A maxillary circumferential retainer was also worn at night.

At 18 months post-treatment follow-up, the results were well maintained (Figure 12-38, *P–R*).

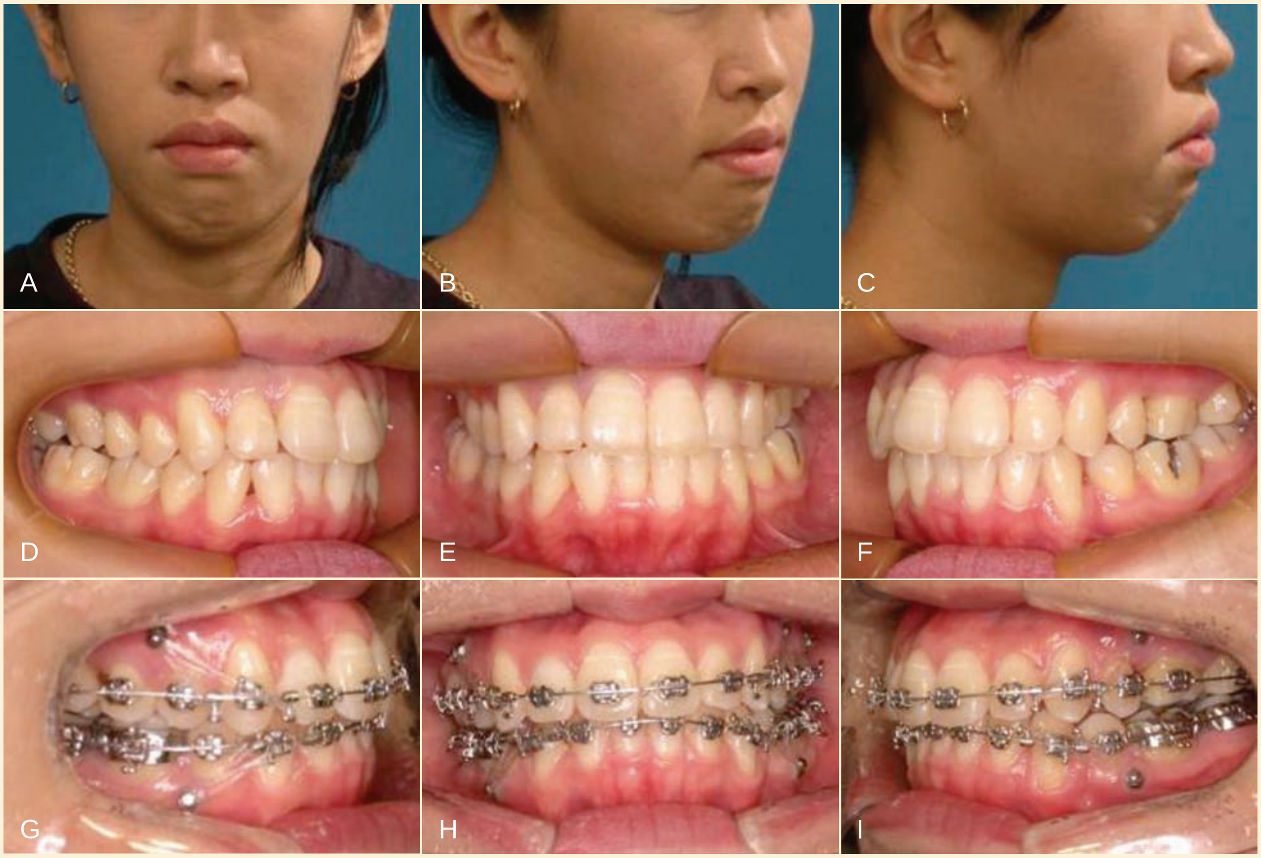


FIGURE 12-38 **A–C,** Facial views prior to treatment. **D–F,** Intraoral views prior to treatment. **G–I,** Intraoral view during treatment.

Continued

CASE STUDY 12-1 **NONSURGICAL CORRECTION OF VERTICAL EXCESS—cont'd**

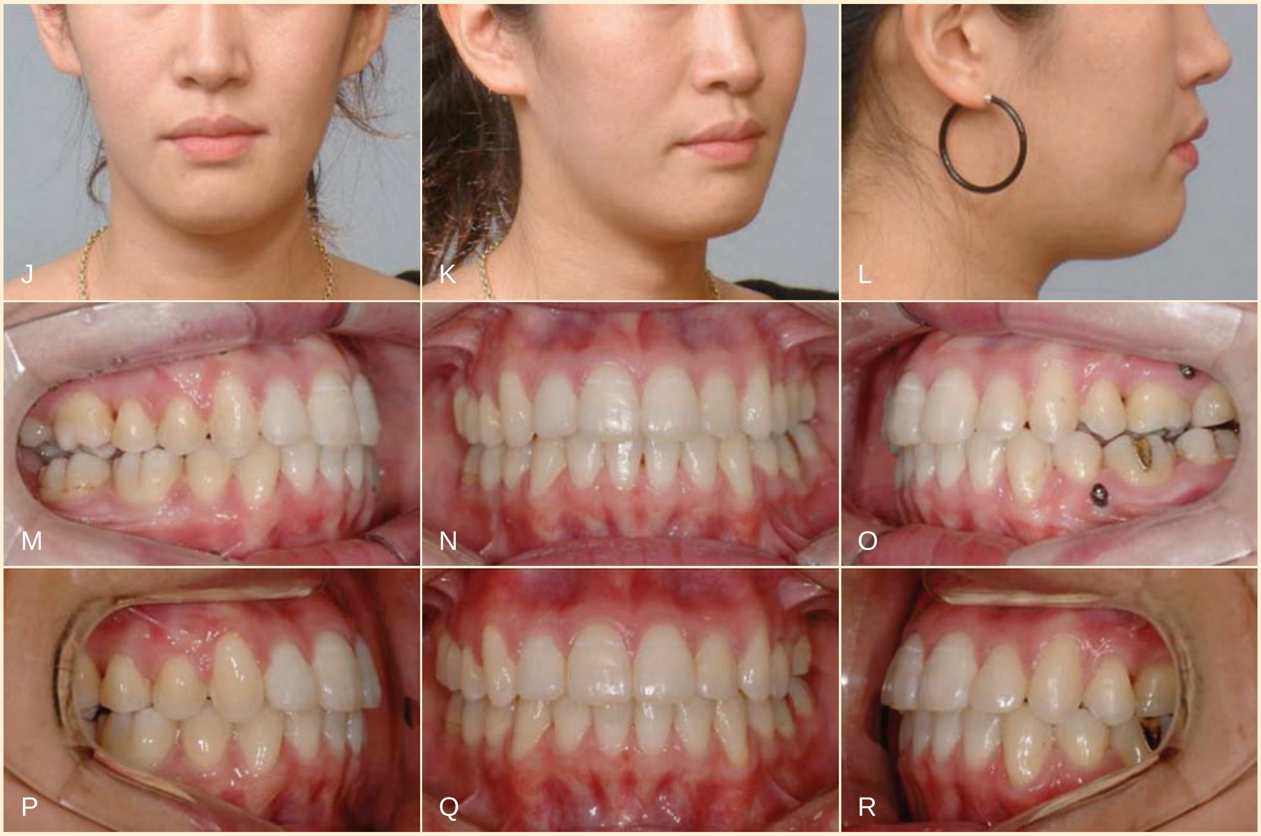


FIGURE 12-38, cont'd **J–L,** Facial views at the completion of active treatment. **M–O,** Intraoral views at the completion of active treatment. **P–R,** Intraoral views 18 months after completion of active treatment.

CASE STUDY 12-1

NONSURGICAL CORRECTION OF VERTICAL EXCESS—cont'd

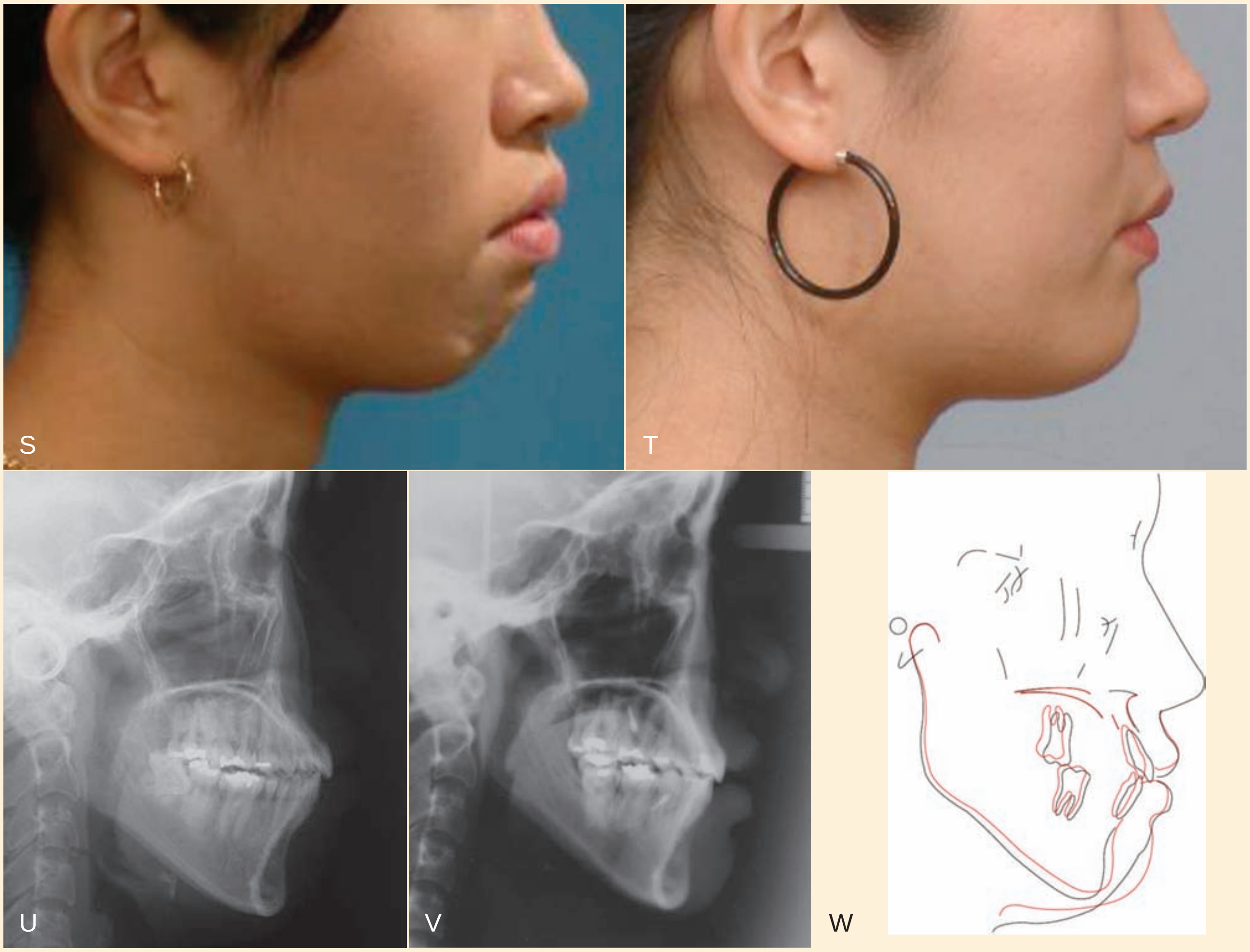


FIGURE 12-38, cont'd **S,** Profile view prior to treatment. **T,** Profile view at the completion of active treatment. **U,** Cephalometric radiograph prior to treatment. **V,** Cephalometric radiograph at the completion of active treatment. **W,** Cephalometric superimpositions.

CASE STUDY 12-2 CORRECTION OF OCCLUSAL CANT AND MIDLINE

Maxillary Molars Intrusion with Mandibular Molars Extrusion

Young-Chel Park

The patient was a 22-year-old man whose chief complaint was "my orthodontic treatment was finished 2 months ago, but my chin has slanted to one side after treatment."

He presented with TMJ symptoms of intermittent pain and clicking on the left TMJ and the upper left first premolar had been extracted. Clinically, the patient's maxillary dentition was canted downward on the right. The patient also exhibited upper and lower midline deviations of approximately 2 mm to the left from the facial midline at maximum intercuspation (Figure 12-39, *F*). A significant lateral shift was noted from centric relation to maximum intercuspation, while the lower dental midline coincided with the facial midline in centric relation (Figure 12-39, *I*). Facial examination revealed that the chin deviated to the left with canted lips at maximum intercuspation, but this deviation was alleviated once in centric relation.

Radiographic examination confirmed that the mandibular asymmetry was due to a significant lateral shift from centric relation to maximum intercuspation. The upper right first molar was 3.3 mm lower than the upper left first molar (Figure 12-39, *K*).

There are two possible options to correct such canting. The first is surgical correction of the maxilla, and the second is nonsurgical correction using TADs to intrude the maxillary molars. The patient opted for the nonsurgical treatment plan.

The treatment plan called for intrusion and distalization of the upper right molars in order to correct maxillary canting as well as the

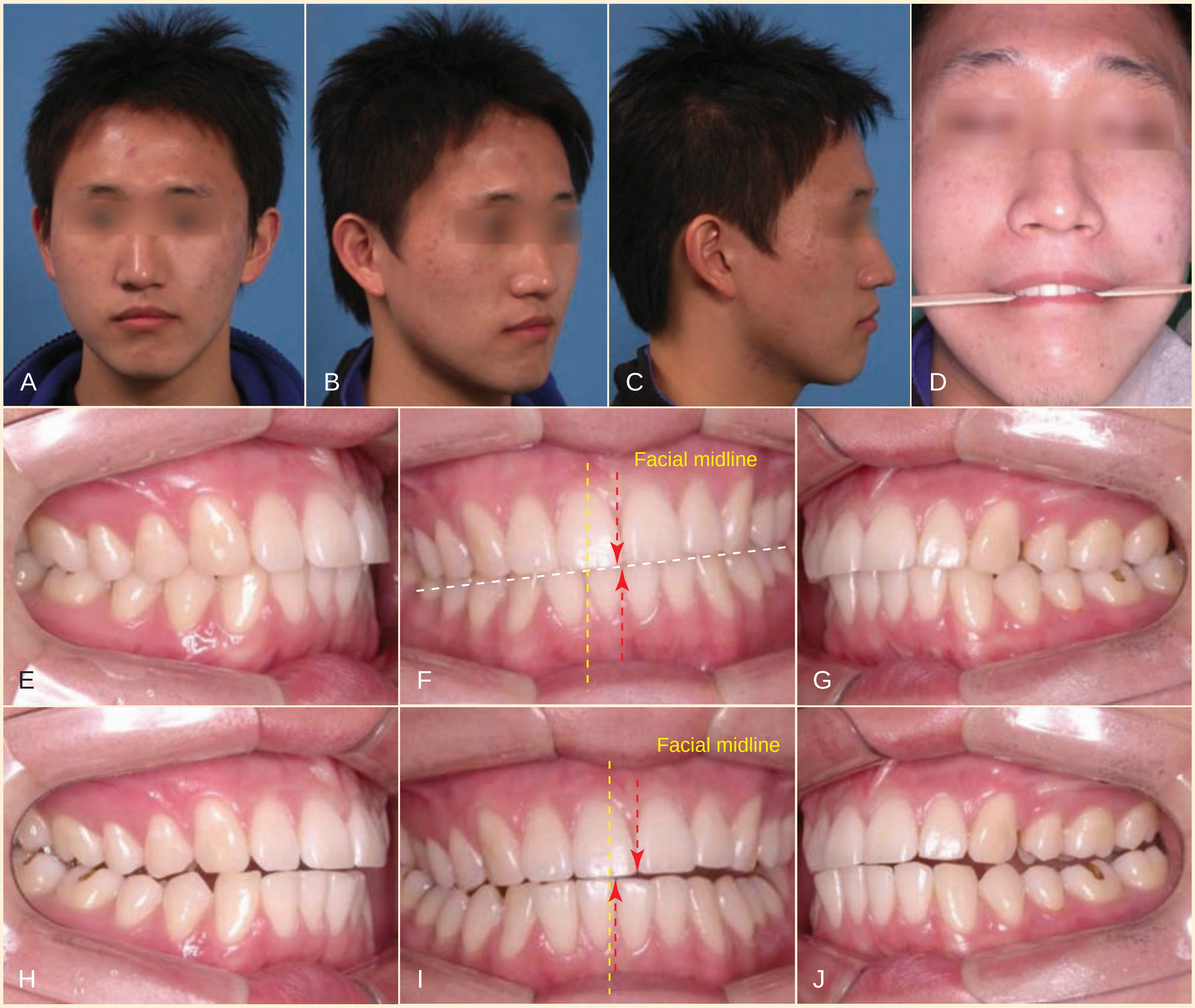


FIGURE 12-39 **A–C,** Extraoral views prior to treatment. **D,** The patient exhibited occlusal plane canting with a tongue blade. **E–G,** Intraoral views prior to treatment in centric occlusion (CO). **H–J,** Intraoral views prior to treatment in centric relation (CR).

CASE STUDY 12-2

CORRECTION OF OCCLUSAL CANT AND MIDLINE—cont'd

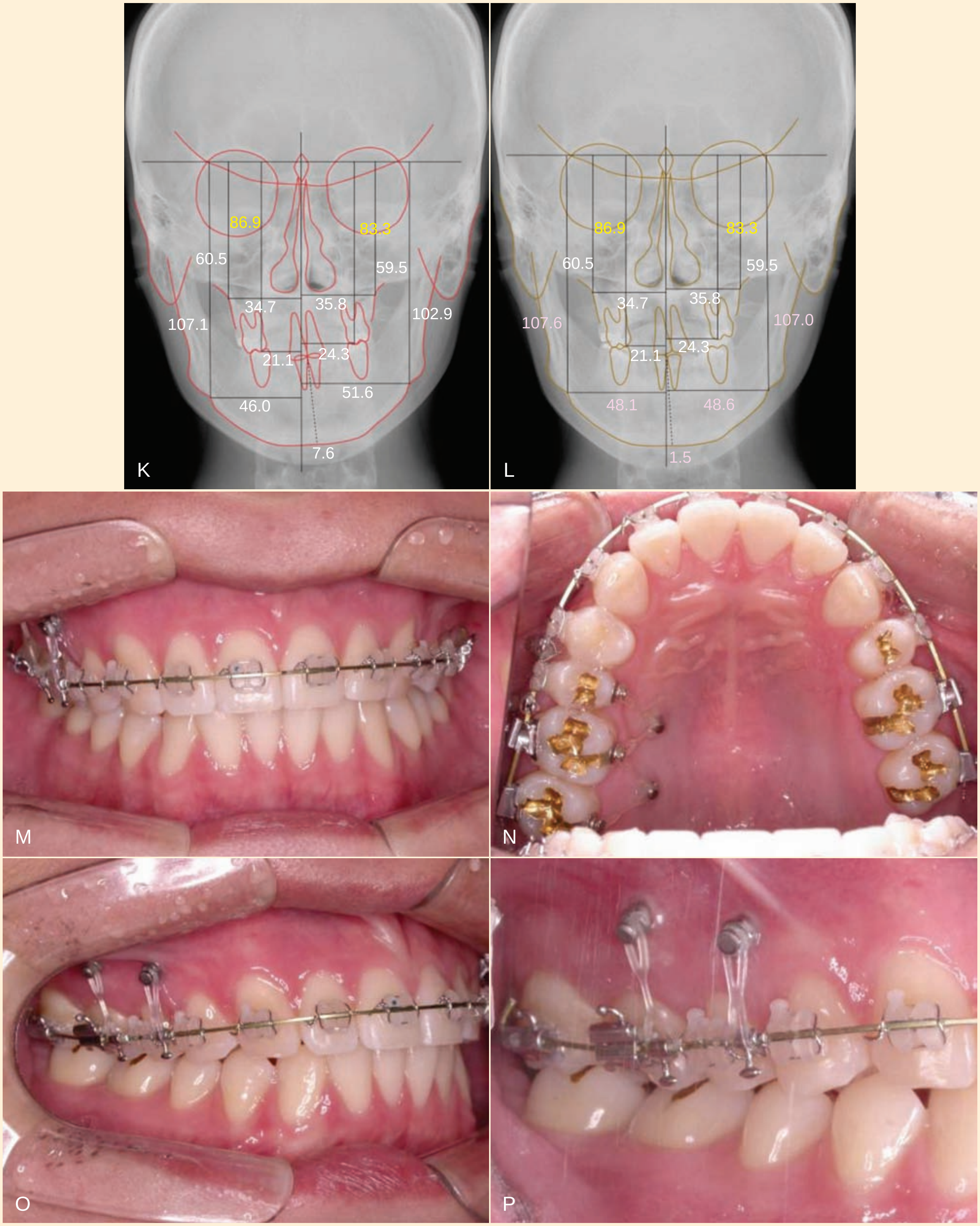


FIGURE 12-39, cont'd **K,** PA cephalometric radiograph in centric occlusion. **L,** PA cephalometric radiograph in centric relation. **M–P,** During treatment, the maxillary working archwire and mini-implants were placed and intrusion of the upper right molars was initiated.

Continued

CASE STUDY 12-2 CORRECTION OF OCCLUSAL CANT AND MIDLINE—cont'd

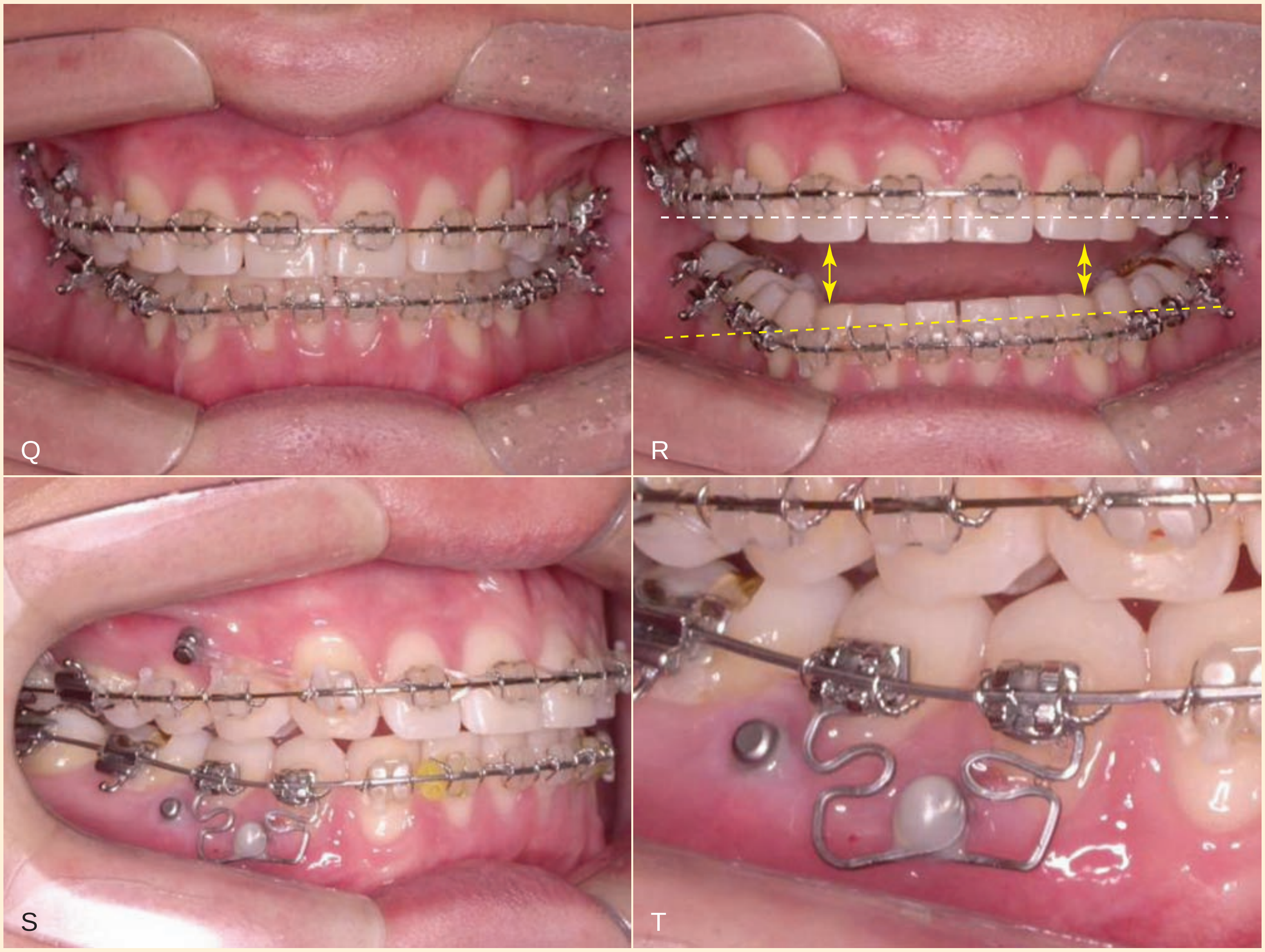


FIGURE 12-39, cont'd **Q, R,** 12 months of treatment. The right maxillary molars were intruded and the differential interocclusal space is shown. **S, T,** 12 months of treatment. Intraoral view with mandibular mini-implants and extrusion spring.

midline deviation, and to guide the mandible to the centric relation position.

Five mini-implants, 1.8 mm in diameter and 7.0 mm in length, were placed in the buccal and palatal area (Figure 12-39, *M, N, O,* and *P*).

After 10 months of treatment, the upper right molars were intruded and distalized. The canting of occlusal plane improved and the mandible was also guided into centric relation (Figure 12-39, *Q, R*).

After 12 months of treatment, one Orlus mini-implant, 1.6 mm in diameter and 7.0 mm in length, was placed on the right buccal slope of the mandible. Then an extrusion spring, made of 0.016 × 0.022-inch TMA (Ormco) wire, was positioned to extrude the lower right posterior teeth. The spring was connected and bonded to the TADs and then applied to the bracket bases to produce an extrusive force (Figure 12-39, *S, T*).

At 18 months after the start of treatment, the appliances were removed and fixed retainers were used (Figure 12-40, *A–F*). Additionally, an active retainer using mini-implants in the maxillary arch was worn at night (Figure 12-40, *H–J*).

The occlusal and mandibular planes rotated 6.2 degrees and 7.5 degrees, respectively.

Menton, therefore, moved 6.4 mm to the right and the facial asymmetry improved (Figure 12-40, *G*).

At a follow-up examination 27 months after the end of treatment, the results were well maintained (Figure 12-40, *K–M*).

CASE STUDY 12-2 CORRECTION OF OCCLUSAL CANT AND MIDLINE—cont'd

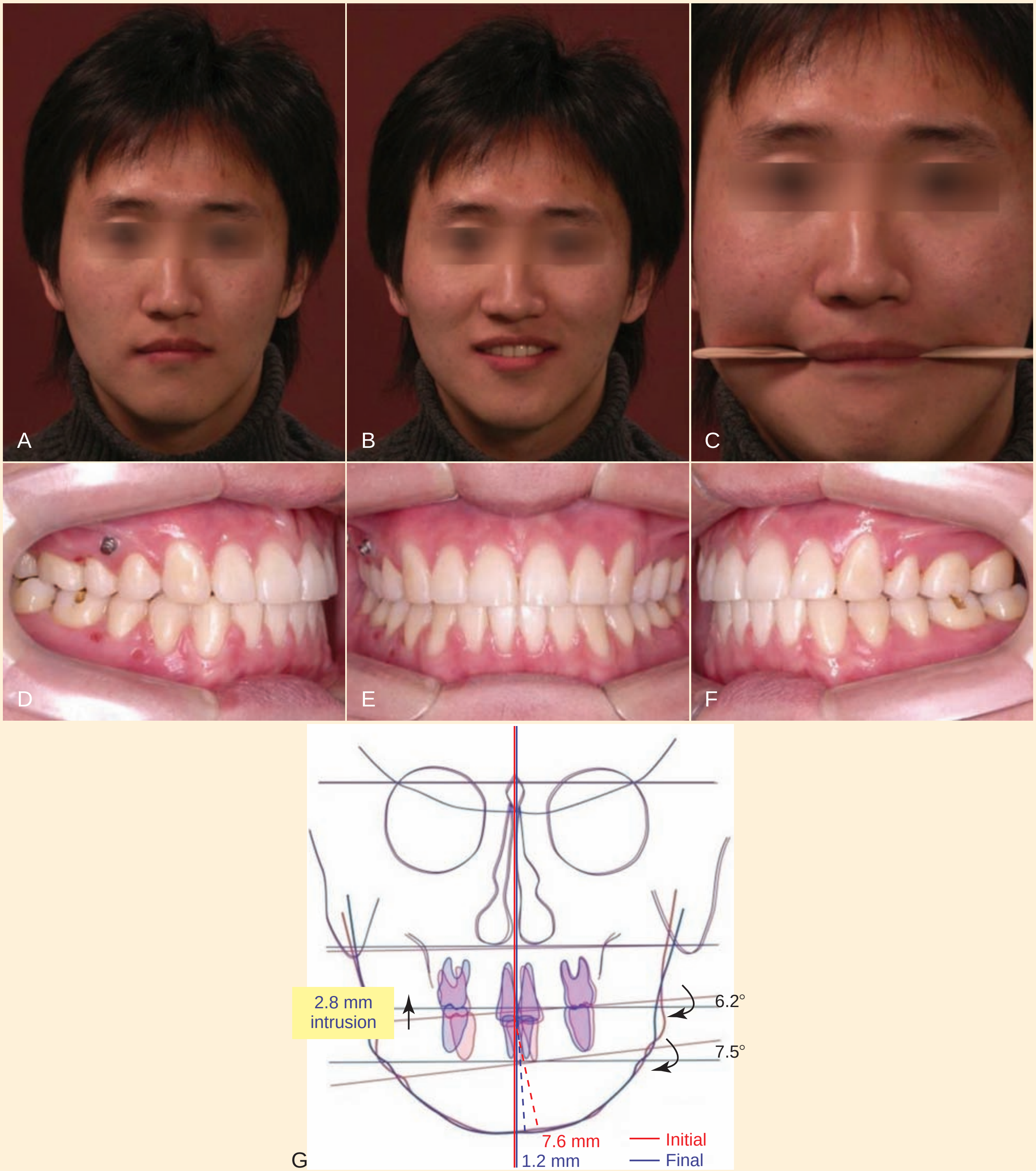


FIGURE 12-40 **A, B,** Extraoral views at the completion of treatment. **C,** A flat occlusal plane shown with a tongue blade. **D–F,** Intraoral views at the completion of treatment, **G,** Superimposition of PA cephalometric radiographs.

Continued

CASE STUDY 12-2

CORRECTION OF OCCLUSAL CANT AND MIDLINE—cont'd

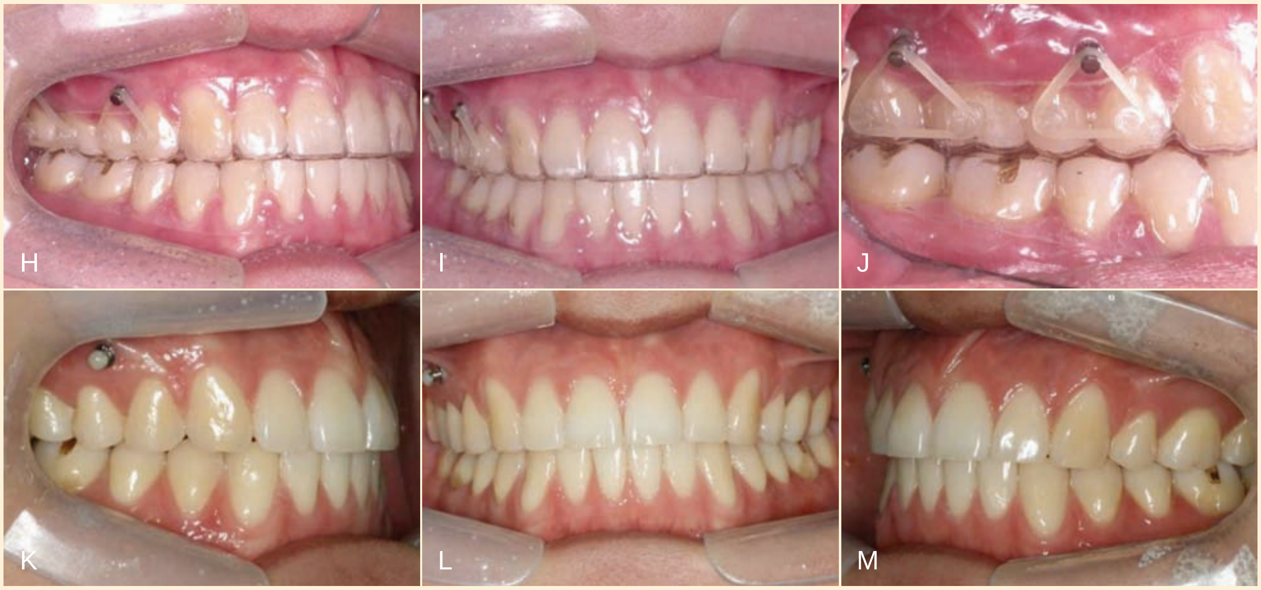


FIGURE 12-40, cont'd **H–J.** Intraoral view with active retainer. **K–M,** Intraoral views at 27 months' retention.

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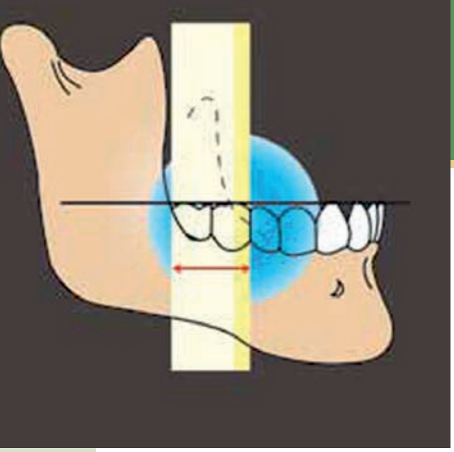

CHAPTER 13

Interceptive Guidance of Occlusion with Emphasis on Diagnosis

Jack G. Dale, Hali C. Dale

> *As we learn more about growth and its potentials, more about the influences of function on the developing denture, and more about the normal mediodistal position of the denture in its relation to basal jawbones and head structures, we will acquire a better understanding of when and how to intervene in the guidance of growth processes so that Nature may better approximate her growth plan for the individual patient. In other words, knowledge will gradually replace harsh mechanics, and in the not-too-distant future the vast majority of orthodontic treatment will be carried out during the mixed-dentition period of growth and development and prior to the difficult age of adolescence.*[79]
>
> **Charles H. Tweed**

OUTLINE

- **Diagnostic Records**
  - Intraoral, Panoral or Cone-Beam Computed Tomography Images
  - Cephalometric Radiographs
  - Facial Photographs
  - Study Models
  - Intraoral Photographs
- **Diagnosis**
  - The Face
  - Proportional Facial Analysis
    - *The Standard*
    - *Alveolodental Protrusion*
    - *Alveolodental Retrusion*
    - *Prognathism*
    - *Retrognathism*
  - The Teeth
    - *Clinical Analysis*
    - *Dental Development in the Mixed Dentition*
  - Total Space Analysis
    - *Conventional Method*
    - *Tweed Method*
    - *Total Space Analysis*
  - Timing of Guided Primary Tooth Removal
- **Treatment**
- **Class I Treatment**
  - Treatment Procedures:
    - Interceptive Guidance, Active Treatment
      - *Serial Extraction in Class I Treatment*
  - Typical Patient for Serial Extraction
- **Key Measurements for Diagnosis and Case Evaluation**

The term *serial extraction* was first introduced by Kjellgren[1,2] in 1929. Special knowledge is required to carry out this procedure successfully. Unfortunately, Kjellgren's phrase resulted in the indiscriminate removal of teeth by individuals who have not appreciated the requisite knowledge. A common misconception is that the procedure is easy because it implies simply the removal of teeth serially.

Hotz,[3] however, referred to the procedure as *guidance of eruption*. This is a better title than Kjellgren's because it implies that knowledge of growth and development is necessary to direct the teeth as they erupt into occlusion. The term *guidance of occlusion* is even more appropriate because clinicians are interested in the final destination of eruption: the occlusion. One must have a thorough understanding of growth and development with all its ramifications and must be aware of occlusion of the dentition, with its relationship to the craniofacial structures and function. This chapter discusses the serial extraction of the primary teeth to guide the eruption of the permanent teeth into a favorable occlusion to intercept, in part, the occurrence of a major malocclusion.

When the practitioner is contemplating the correction of an orthodontic problem, the most crucial decision to

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make is whether teeth should be extracted. Even more demanding is adding morphogenetic pattern and the dimensions of time, complicating that with the growth and development of the dentition and the craniofacial complex and carrying out the procedure serially.[2]

Serial extraction is not easy, as so many mistakenly believe. Serial extraction should never be initiated without a comprehensive diagnosis. Teeth may be extracted with the greatest of ease during a so-called serial extraction procedure. However, if the basic principles of diagnosis are ignored, the result will be failure and disappointment. Serial extraction will be not only injurious to the patient but also injurious to the reputation of the practitioner and ultimately to the profession. Legal concerns regarding risk management include promiscuous extraction.[4]

Unfortunately, since Bunon[5] introduced serial extraction to the profession 268 years ago, it has been grossly misunderstood. Lack of understanding and knowledge has produced disastrous results, including a deterioration of the dentition and facial balance. Serial extraction has been criticized and maligned unfairly by individuals who have never used the procedure in practice or acquired the necessary knowledge to perform it well.

If serial extraction is based on a thorough diagnosis and carried out carefully and properly on a select group of patients, the procedure can be an excellent and valuable treatment. Serial extraction can reduce appliance treatment time, the cost of treatment, discomfort to the patient, potential iatrogenic sequelae, and time lost by the patient and the parents.

To intercept a malocclusion as early as possible and to reduce or, in rare instances, avoid fixed appliance mechanotherapy at the sensitive teenage period is logical. Why allow an unfavorable dental, skeletal, or soft tissue relationship to exist for a number of years if it can be corrected, or significantly improved, early with a minimum of appliance treatment time?

Before attempting the treatment of an orthodontic patient using guidance of occlusion, the practitioner must be prepared to meet the challenge of diagnosis. Without question, the secret of success in orthodontic treatment is a thorough understanding of mixed-dentition diagnosis. The orthodontist can have the most comprehensive and sophisticated treatment plan at work in the patient's mouth; however, if the plan is implemented in the wrong patient, treatment will fail. This chapter discusses guidance of occlusion with a special emphasis on diagnosis.

Charles Tweed, whose words are quoted at the beginning of this chapter, was a man who devoted more than 40 years of his life to the treatment of the permanent dentition and the development of precision edgewise mechanotherapy, sometimes referred to as "harsh mechanics." However, during the last 13 years of his life he was vitally interested in treatment during the mixed-dentition period, including pre-orthodontic guidance, guidance of occlusion, and serial extraction.

Tweed and many others found that serial extraction, especially in Class I tooth-size/jaw-size discrepancy malocclusions, improves the alignment of the teeth when they emerge into the oral cavity. As a result it creates a better environment "so that Nature may better approximate her growth plan." Tweed also discovered that the interception of dentofacial deformities using "growth and its potentials" and biologic principles rather than "harsh mechanics" was an exhilarating and rewarding experience.

Early consideration of the corrective measures necessary to remedy any type of malocclusion should be a prime concern of the practitioner. Whatever method is chosen, treatment time should be at a minimum.[6]

Considering the current trends of avoiding bands, lingual appliances, and the integrated use of aligners, serial extraction becomes even more important. There are increasing concerns of tissue damage and the iatrogenic potential of our armamentaria and materia technica (see Chapters 9 and 11).[4] The best way to hide appliances is to not use them or at least to diminish their use. By using the benefits of serial extraction in Class I malocclusions, orthodontists can concentrate more fully on the time-consuming and technically demanding Class II and III malocclusions; thus, these orthodontists increase their usefulness to their profession and to society.

Serial extraction often has been criticized as being a bad procedure, and it certainly can be more harmful than beneficial if not done properly (Figure 13-1). The two girls in Figures 13-2 and 13-3 are 13 years of age, just at the beginning of adolescence. The girl in Figure 13-2 has a severe Class I tooth-size/jaw-size discrepancy. Her treatment required the extraction of four premolar teeth and 30 months of mechanotherapy beginning at 13 years. The retention period was prolonged because the teeth had been allowed to remain in a crowded irregular relationship for several years. The girl in Figure 13-3 had a similar malocclusion, but her treatment was completed

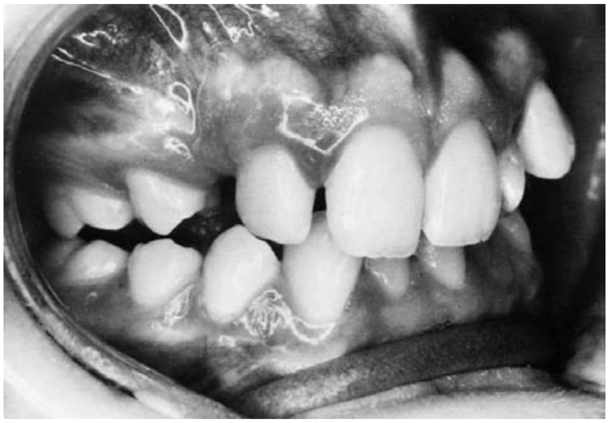


FIGURE 13-1 Class II, Division 2, malocclusion with an impacted permanent maxillary right canine. During a misguided serial extraction program, one mandibular incisor and the maxillary right first premolar were extracted.

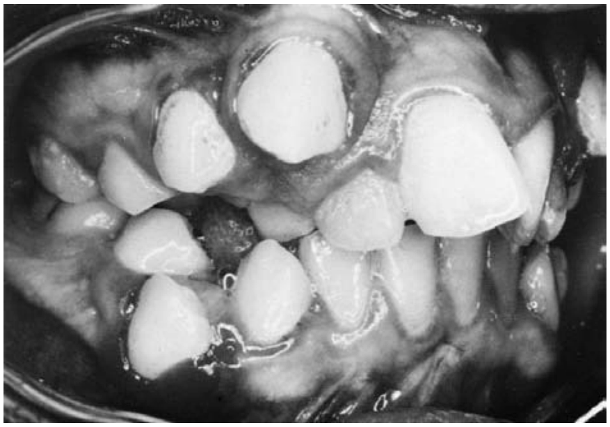


FIGURE 13-2 A 13-year-old girl who did not have the benefit of serial extraction and early treatment.

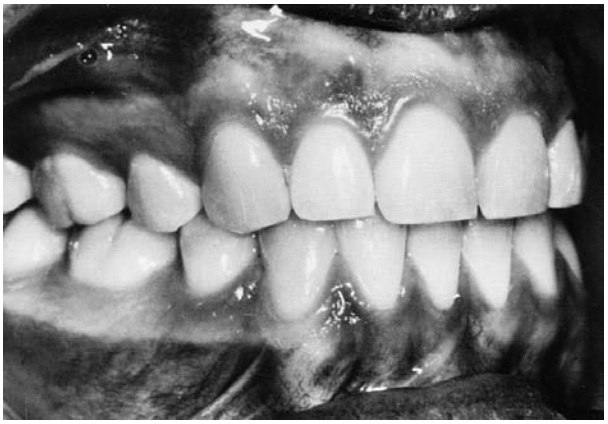


FIGURE 13-3 A 13-year-old girl who had the benefit of serial extraction and early treatment.

by 13 years. Serial extraction was begun at 8 years, and the multi-bonded appliance was inserted at 12 years. The retention period was minimal. Thus, two girls with similar malocclusions were treated differently. Whereas one was just beginning 30 months of treatment at 13 years, the other already was finished and had a more stable result.

The recommended routine office procedure performed before serial extraction requires a complete orthodontic evaluation including a comprehensive patient history, a thorough clinical and diagnostic records evaluation, followed by an appropriate parental/guardian consultation (see Chapters 1 and 2).

DIAGNOSTIC RECORDS

A complete set of diagnostic records is acquired to develop the diagnosis including panoral radiographs and cephalometric radiographs (or cone-beam computed tomography [CBCT]), oriented facial photographs, study models, and intraoral photographs of the dentition. The objective of taking quality records is to secure clinical accuracy for the purpose of establishing a sound diagnosis and being able to communicate the therapeutic needs to the parent and patient as well as general or pediatric dentist.

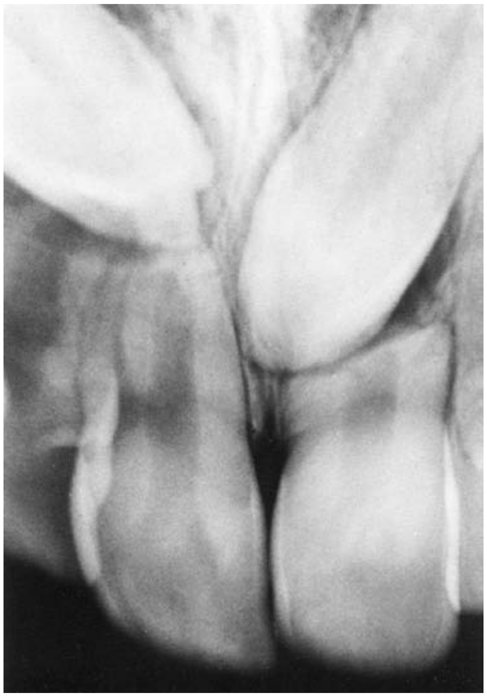


FIGURE 13-4 Root resorption of the maxillary central incisors by impacted canines. *(From Dale JG: Trauma: its influence on orthodontic treatment planning,* Dent Clin North Am *26:565, 1982.)*

Intraoral, Panoral or Cone-Beam Computed Tomography Images

Dental radiographs must be taken for the following reasons:

1. Protection of the patient and documentation for the orthodontist
2. Detection of congenital absences of teeth
3. Detection of supernumerary teeth
4. Evaluation of the dental health of the permanent teeth (detection of pathologic conditions in the early stages)
5. Assessment of trauma to the teeth after an injury
6. Detection of evidence of a true hereditary tooth-size/jaw-size discrepancy such as the resorptive pattern on the mesial of the roots of the primary canines
7. Determination of dental age of the patient by assessing the length of the roots of permanent unerupted teeth and the amount of resorption of primary teeth, as in dental age analysis
8. Calculation of the total space analysis (see later Figures 13-46 to 13-56)
9. Detection of root resorption before, and by means of comparison, during and after treatment (Figure 13-4)
10. Evaluation of third molars before, during, and after treatment

11. Posttreatment radiographic evaluation allows for appraisal and documentation of the dental health after orthodontic treatment

Cephalometric Radiographs

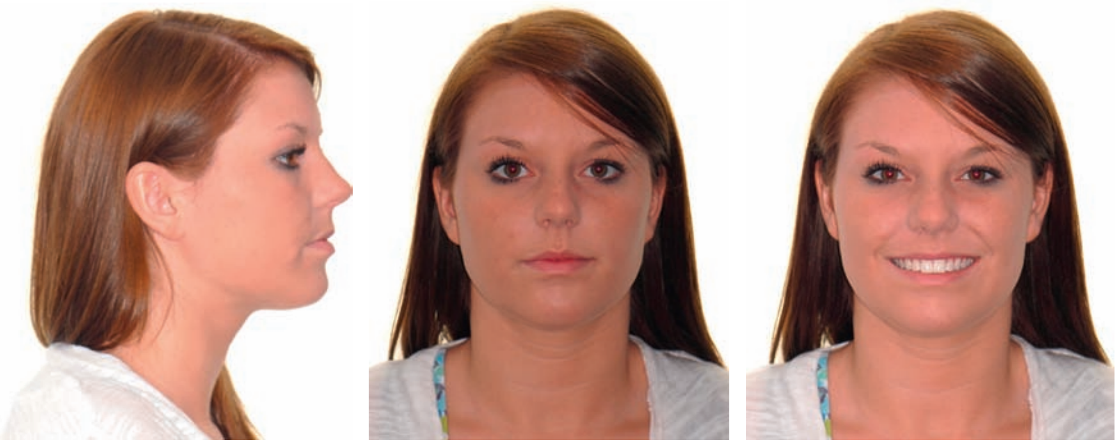
Cephalometric radiographs are used for the following:

1. Evaluation of craniofaciodental relationships before treatment
2. Assessment of the soft tissue matrix
3. Classification of facial patterns (as in the proportional facial analysis) (see later Figures 13-8 to 13-17)
4. Calculation of tooth-size/jaw-size discrepancies (as in the total space analysis)
5. Determination of mandibular rest position (as in the occlusal curves analysis)
6. Prediction of growth and development
7. As a basis for monitoring of skeletodental relationships during treatment
8. Detection of pathologic conditions before and after treatment
9. Assessment of trauma after facial injuries
10. These radiographs and their pretreatment and posttreatment evaluation allow for long-term improvement in treatment planning

Facial Photographs

Figures 13-5 and 13-6 illustrate the requirements of the American Board of Orthodontics for oriented facial and intraoral photographs.[1] Facial patterns play an important role in diagnosis and treatment planning, especially in serial extraction. From a practical standpoint, the photographs allow the orthodontist to better identify the patient. The prime objective of diagnosis and treatment in relation to the face should be the creation of harmony and balance: a favorable, proportionate relationship between the teeth, skeletal pattern, and soft tissue matrix, including the profile. Like cephalometric radiographs, facial patterns are invaluable for the following:

1. Evaluation and documentation of craniofacial (and dental) relationships and proportions before treatment



Requirements:

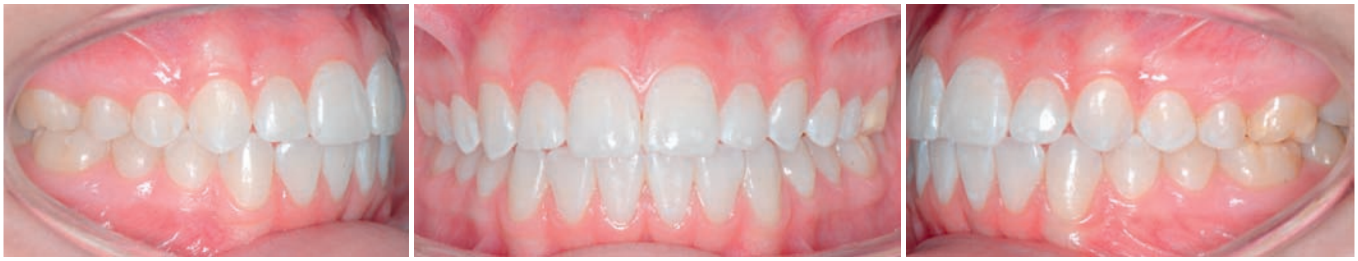
Lateral view:
- Ears displayed
- Full face displayed in natural head position
- Left eyelash slightly visible

Frontal views:
- Teeth in occlusion
- Eyes are open and looking into camera
- Ears exposed
- Lips relaxed and in contact
- No distracting eyewear or jewelry
- Cropped to reveal facial symmetry and balance
- Inter-pupillary line bisecting the frame revealing top of shoulders and neck
- Use the same format for the smiling and nonsmiling photographs

FIGURE 13-5 American Board of Orthodontics requirements for facial photographs. *(From American Board of Orthodontics:* Specific instructions for candidates, *St Louis, 2011, Author.* www.americanboardortho.com*)*

- Mid-palatal raphe centered
- Frame the entire arch with minimal amount of soft tissue displayed

- Fill the frame with the entire mandibular arch at least through the first molars
- Labial surface of the central incisors parallel to the bottom of the frame
- Midline centered in the frame



- Anteriorly include the contralateral central incisor
- Posteriorly include at least the first molars
- Occlusal plane should be parallel to the frame

- Occlusal plane should be horizontal and should bisect the photograph
- There should be equal display of the posterior dentition

- Use the same format as for the right lateral intra-oral photograph

FIGURE 13-6 American Board of Orthodontics requirements for intraoral photographs. *(From American Board of Orthodontics: Specific instructions for candidates, St Louis, 2011, Author.* www.americanboardortho.com*)*

2. Assessment of soft tissue profile and muscle balance
3. Proportional facial analysis and evaluation of symmetry
4. Total space analysis in tandem with occlusal curves analysis
5. Monitoring of treatment progress
6. These photographs and their pretreatment and posttreatment evaluation allow for long-term improvement in treatment planning

Study Models

Study models provide a three-dimensional record of the dentition and are essential for many reasons.[1] Although CBCT radiographic imaging and occlusal scanning and other imaging technologies may eventually allow us to replace this record, models are used for the following:

1. To calculate total space analysis
2. To assess and document the dental anatomy
3. To assess and document the intercuspation
4. To assess and document arch form
5. To assess and document the curves of occlusion (occlusal curves analysis)
6. To evaluate functional occlusion, potentially with the aid of articulators
7. As a basis from which to measure progress during treatment
8. To detect abnormalities (e.g., localized enlargements and distortion of arch form)
9. These records and their pretreatment and posttreatment evaluation allow for long-term improvement in treatment planning

Intraoral Photographs

Figure 13-6 illustrates the requirements of the American Board of Orthodontics for intraoral photographs.[7]

Intraoral photographs are valuable to evaluate and document the immediate soft and hard tissue relationships surrounding the teeth. They present a time-stamped record of the visual characteristics of the gingiva as well as the enamel prior to placement of any appliances. Intraoral photographs add the dimension of color to the records, which aids in assessing and recording the health or disease of the teeth and soft tissue structures.[4]

Regarding serial extraction, photographs allow the clinician to record the steps in the technique, frequently without making study models. This is important for self-evaluation and discussion with patients and parents as well as our general and pediatric dental colleagues.[8] A picture is truly worth a thousand words, and with the ability to share digital images, we are better able to communicate and consult on important treatment decisions. The ability of a lay parent/guardian to see problems that have been identified, visualize changes, and share with family throughout treatment is a great benefit as well.

DIAGNOSIS

To differentiate, categorize, and treat specifically, successfully, and routinely requires an understanding of the fundamental principles of diagnosis. Several analyses related to the face and teeth are discussed in this section. These examples of the procedures should be followed if treatment is to be successful and serial extraction effective.

The Face

The infant face is not simply a miniature of the adult face (Figure 13-7). The linkage of the terms growth and development indicates that the enlargement of the face involves more than the progressive increases in size. Growth is a differential process, in which some parts enlarge more or less than others and in a multitude of directions. Growth is a gradual maturational process taking many years and requiring a succession of changes in regional proportions and relationships of various parts. Many localized alterations occur that are associated with a continuous process of soft and hard tissue remodeling. An understanding of the mechanisms

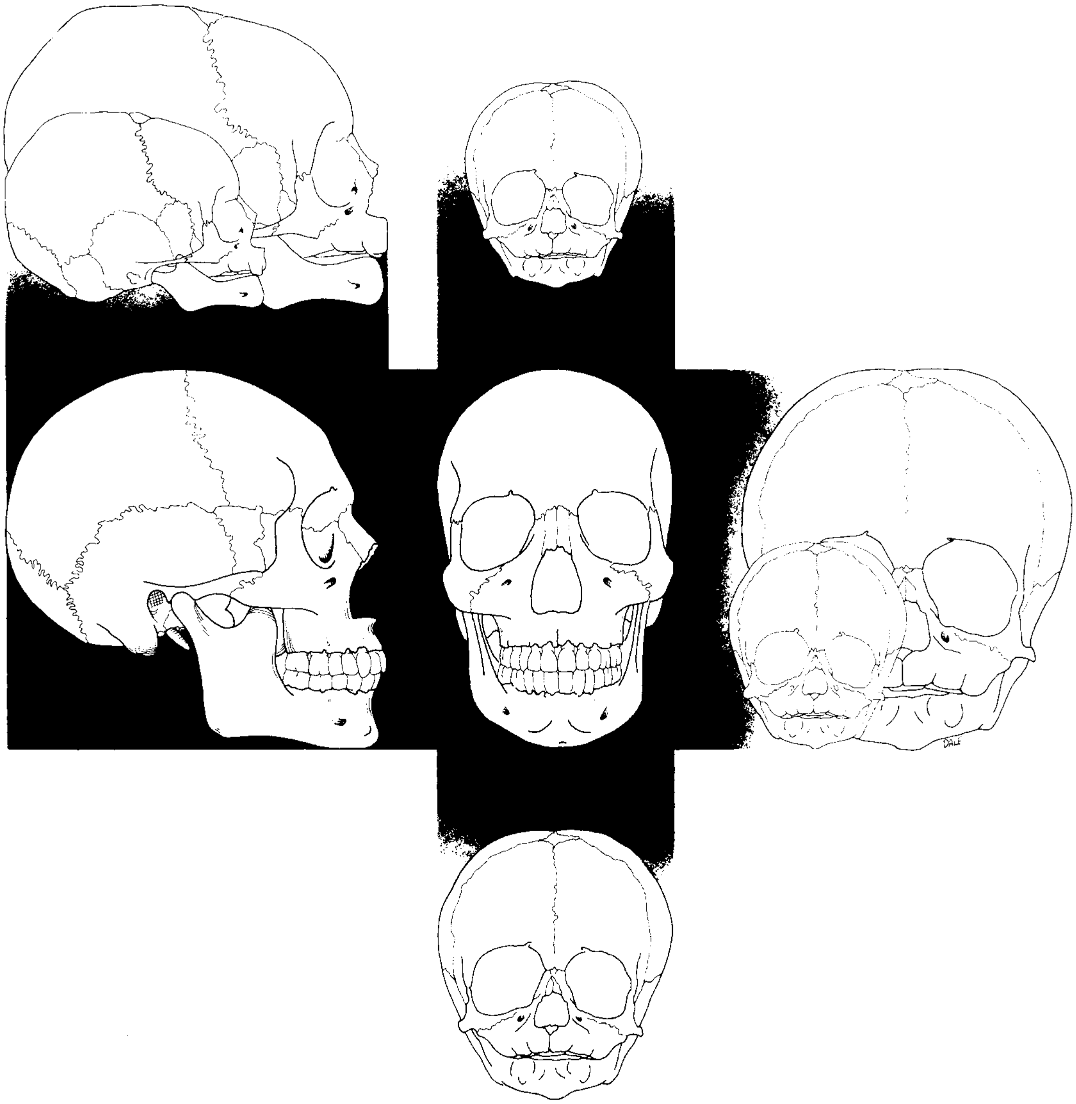


FIGURE 13-7 Changes in facial proportions throughout growth and development from infancy to maturity. To show the regional differences in height, depth, and breadth, the newborn skull has been enlarged to the same size as the adult skull. *(From Dale JG: Childhood facial growth and development. In Ten Cate AR, et al:* Oral histology: Development, structure, and function*, St Louis, 1998, Mosby.)*

of growth and development of the face is essential to the practice of dentistry (see Chapter 8). To achieve this understanding, one must have some knowledge of faces.

Normal growth is unbalanced and therefore progressive and, noticeably, alterations in facial form and pattern take place. Differential growth processes not only produce a wide range of topographic facial variations but also constitute the developmental basis for malocclusions and congenital facial abnormalities. To control and use the complex processes of growth in clinical procedures, an understanding of various concepts is essential for dentists.

Proportional Facial Analysis

The proportional facial analysis is basically a classification of facial patterns based on the Steiner analysis,[9] the Merrifield and Tweed cephalometric analyses,[10,11] and especially the counterpart analysis of Enlow.[12] Proportional facial analysis includes an evaluation of the following relationships (Figure 13-8, *A*):

- Anterior cranial base (*1, 2*)
- Posterior cranial base (*2, 3*)
- Cranial base angle (*1, 2, 3*)
- Ramus of the mandible (*3, 4*)
- Corpus of the mandible (*4, 5*)
- Gonial angle (*3, 4, 5*)
- Nasomaxillary complex (*6, 7, 8, 9*)
- Maxillary dentition (*10, 11*)
- Mandibular dentition (*12, 13*)

The posterior maxillary (PM) plane is possibly the most significant plane in the craniofacial complex. The plane delineates, naturally, the various anatomic counterparts and is a developmental interface between the series of counterparts in front of and behind it. The posterior maxillary plane thus retains a number of basic relationships throughout the growth process.

The Standard. The standard or orthognathic face, as in Figure 13-8, *B, C*, exhibits a harmonious relationship between the facial structures and the cranium, between the maxilla and the mandible, between the maxilla and the maxillary dentition, between the mandible and the mandibular dentition, between the maxillary dentition and the mandibular dentition, and between the soft tissue profile and the underlying hard tissue structures ("the mesiodistal position of the denture in its relation to the basal jawbones and head structures").[13]

Alveolodental Protrusion.

Class I: Maxillary Mandibular Alveolodental Protrusion. The maxillary and the mandibular dentitions are forward, and the teeth are in a Class I relationship (Figure 13-9). This facial pattern in general responds well to extraction and, when caution is exercised, to serial extraction.[14,15]

Class II: Maxillary Alveolodental Protrusion. The maxillary dentition is forward, and the teeth are in a Class II relationship, but everything else is favorable (Figure 13-10). Routinely, this malocclusion can be treated by the extraction of two maxillary first premolars and by serial extraction in the maxilla only.

Class III. In the interest of brevity and relevance, the Class III category of this analysis will not be included

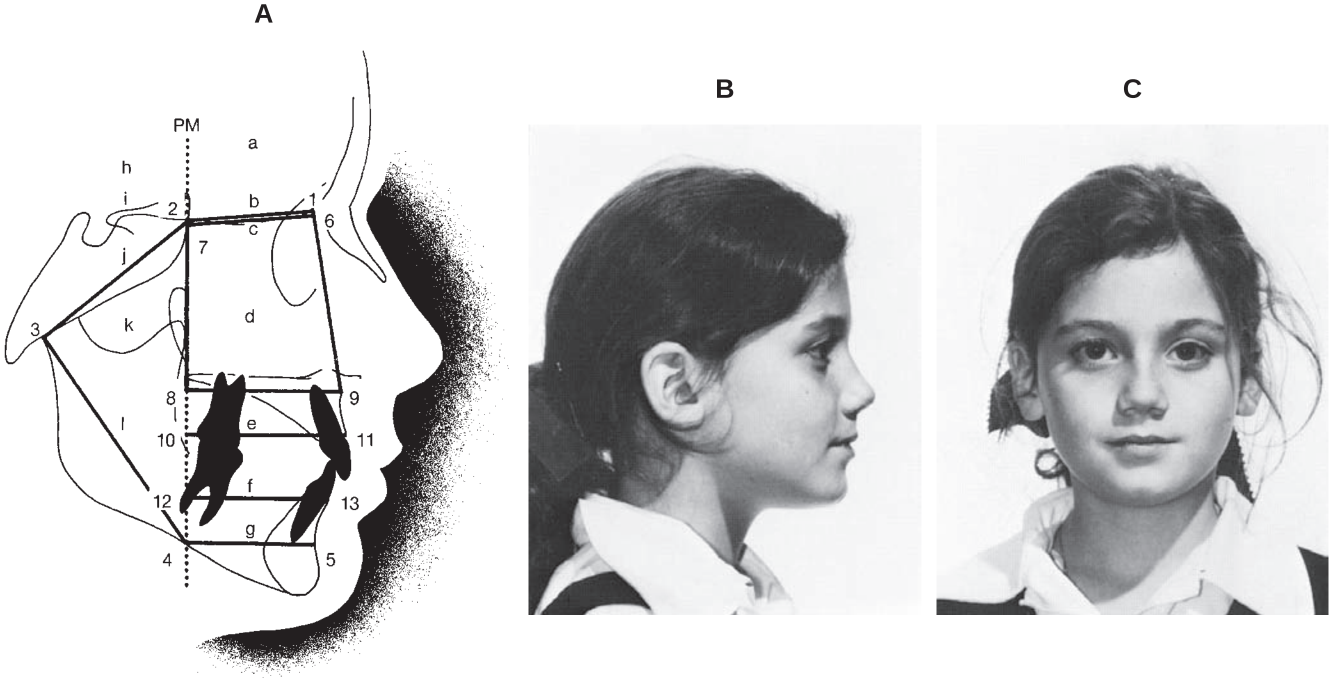


FIGURE 13-8 Standard or orthognathic facial pattern. **A,** The basic units associated with the proportional facial analysis. **B, C,** The patient.

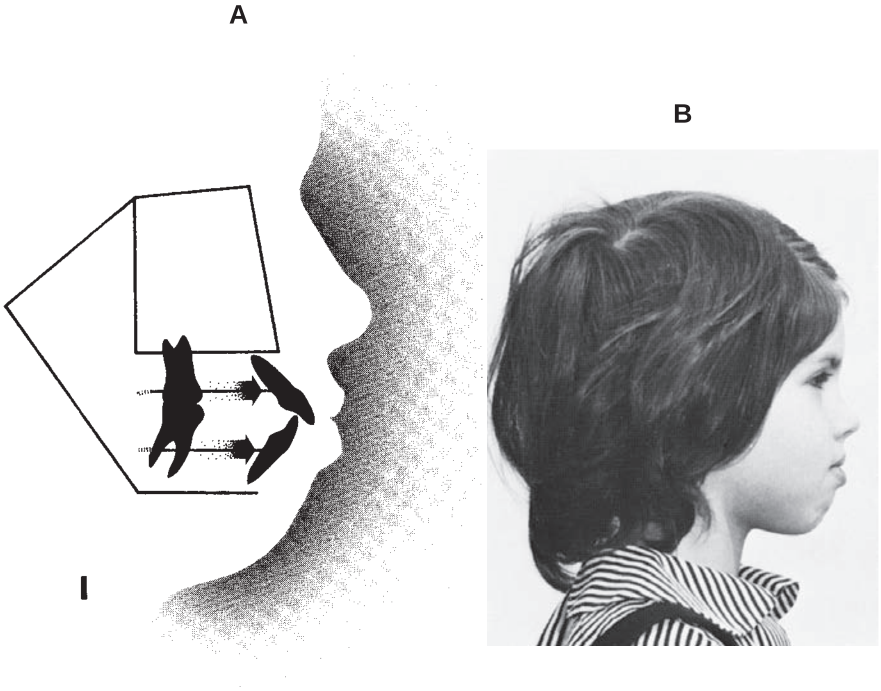


FIGURE 13-9 **A,** Class I maxillary mandibular alveolodental protrusion. **B,** Typical patient profile.

in the discussion. Class III malocclusions are not suitable for serial extraction procedures. Mixed dentition Class III treatment is a complicated undertaking, is often extensive and prolonged, and may have to be repeated (see Chapter 4).

Alveolodental Retrusion.

Class I: Maxillary Mandibular Alveolodental Retrusion. The maxillary and mandibular dentitions are back, and the teeth are in a Class I relationship (Figure 13-11). The orthodontist must be particularly careful in treating this type of facial pattern. If possible, treatment should be done without the extraction of teeth. This appearance can be seen in individuals who have had no orthodontic treatment and in patients who have had treatment with extractions and without. A dished-in face cannot always be avoided, regardless of the treatment.

Class II: Mandibular Alveolodental Retrusion. The mandibular dentition is back, and the teeth are in a Class II relationship (Figure 13-12). Again, the practitioner must be careful about extracting teeth in this type of facial pattern.

Prognathism.

Class I: Maxillary Mandibular Prognathism. In maxillary mandibular prognathism, both jaws are forward and the teeth are in a Class I relationship (Figure 13-13). Often this is a most aesthetic facial pattern. Many motion picture stars exhibit this type of profile. If the teeth are severely crowded, serial extraction should be performed. However, because of the increase in the size of the jaws, extractions are not always indicated.

Class II: Maxillary Prognathism. In maxillary prognathism, the maxilla is forward and the teeth are in a Class II relationship (Figure 13-14). This relationship may be because the maxilla itself is forward or may result from a long anterior cranial base. Also, the cranial base angle may be flat, creating a downward and forward position of the nasomaxillary complex. This in turn may rotate the mandible down and back. These are difficult Class II malocclusions to treat and certainly demand more than serial extraction. The malocclusions are complicated skeletal discrepancies that may require not only comprehensive mechanotherapy but also surgical intervention. Midface protrusions, as they are called sometimes, are difficult profiles to correct satisfactorily by orthodontic treatment alone. The nose, at the end of treatment, often is prominent.

Retrognathism.

Class I: Maxillary Mandibular Retrognathism. In Class I malocclusions exhibiting maxillary mandibular retrognathism, the maxilla and mandible are back in relation to the other craniofacial structures (Figure 13-15). To produce a favorable profile in these patients is difficult because of the lack of horizontal growth and the recessive nature of their profiles. Every effort should be made to encourage a forward development of the jaws. However, this is difficult because the dentition is in a Class I relationship. Over a long time such a profile can become more recessive and, if serial extraction is being done, the orthodontist could be saddled with the blame. To explain to the parents during the case presentation that this patient

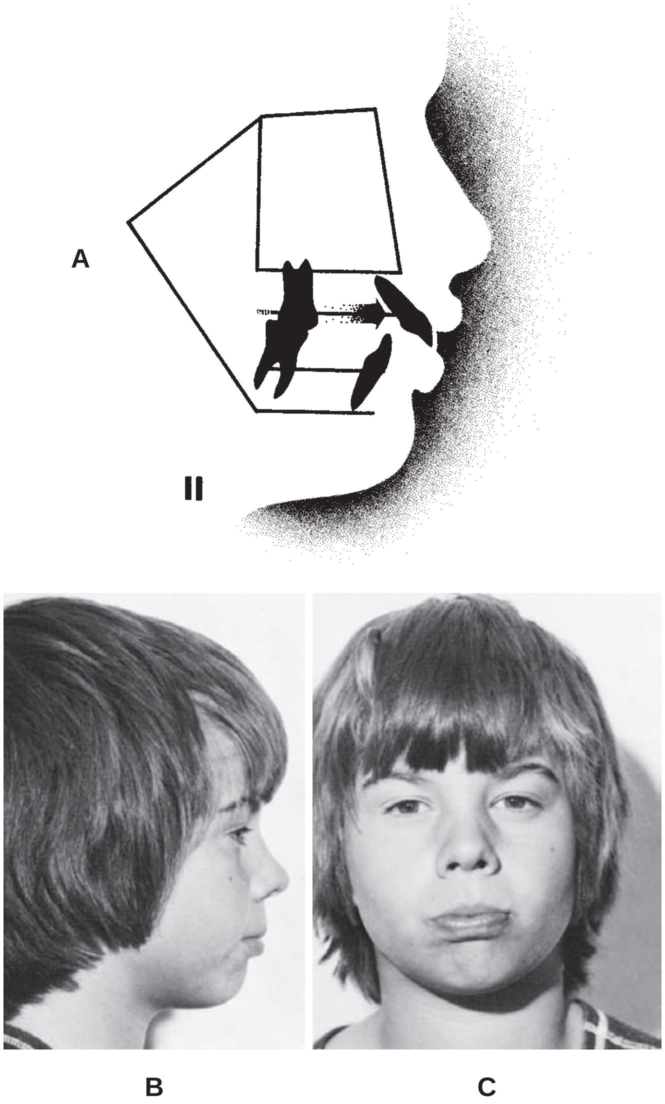


FIGURE 13-10 **A,** Class II maxillary alveolodental protrusion. **B, C,** Typical patient profile and frontal views demonstrating perioral muscle strain.

appears to have an unfavorable growth pattern that may get worse regardless of treatment is important.

Class II: Mandibular Retrognathism. In Class II malocclusions exhibiting mandibular retrognathism, the mandible is back. The corpus of the mandible may be small (Figure 13-16) or the ramus may be narrow. The gonial angle may be proportionately acute. Excessive vertical development may be evident in the nasomaxillary complex (Figures 13-16 & 13-17), which in turn rotates the mandible down and back, producing a retrognathic mandible and a tendency to open bite. If this is the cause of the retrognathic mandible, the treatment of preference may be surgery or, if less extreme, use of temporary anchorage devices (TADs) to intrude posterior dental segments to allow the forward rotation of the mandible. Regardless, a patient with this facial pattern is not a good candidate for serial extraction. McNamara[16] found the most common characteristic of Class II malocclusions to be a retrognathic mandible, with excessive vertical development.

According to the proportional facial analysis, a Class I malocclusion could be associated with a facial pattern characterized by a maxillary mandibular alveolodental protrusion, maxillary mandibular alveolodental retrusion, maxillary mandibular prognathism, maxillary mandibular retrognathism (even orthognathism), or a combination of these features.

What is evident from this analysis is that to treat all Class I malocclusions in the same manner would not be using sound clinical judgment. Class I malocclusions with excessive vertical development of the nasomaxillary area might be treated better by posterior segment impaction with TADS or combined orthodontics and orthognathic surgery or alternate tooth extraction protocols rather than by serial extraction followed by removal of the four first premolars.

Similarly, a Class II malocclusion could be a result from maxillary alveolodental protrusion; mandibular alveolodental retrusion; a prognathic maxilla caused by a forward nasomaxillary complex, long anterior cranial base or flat cranial base angle; a retrognathic mandible caused by a short corpus, narrow ramus, acute gonial angle, and excessive vertical development of the nasomaxillary complex; or a combination of these features.

What is even more evident is that one should give serious thought before using serial extraction in Class II malocclusions. Serial extraction aids in the correction of tooth-size/jaw-size discrepancies but not necessarily in the correction of a Class II relationship. Therefore the orthodontist must be prepared to place appliances for an extended time. The diagnosis is particularly important because permanent teeth other than the four first premolars may be extracted in the treatment of these malocclusions, which is referred to later in the discussion of total space analysis.

The proportional facial analysis describes clearly the multifactorial basis for malocclusion and also explains the way compensation may occur to prevent or minimize a discrepancy. A patient's facial pattern may include a Class I profile with harmony and balance that results from a small cranial base angle (which is a Class III characteristic) and a short corpus (which is a Class II characteristic). Because the maxilla and the mandible tend toward retrognathism, the profile that results is in balance.

Similarly, a combination of factors could result in a more severe malocclusion. A patient might have a Class I malocclusion as a result of excessive vertical development (a Class II characteristic) and a large gonial angle (a Class III characteristic). However, in this instance the two factors do not balance one another but combine to make the malocclusion more severe. This Class I dentition would not be a good candidate for premolar extraction or serial extraction.

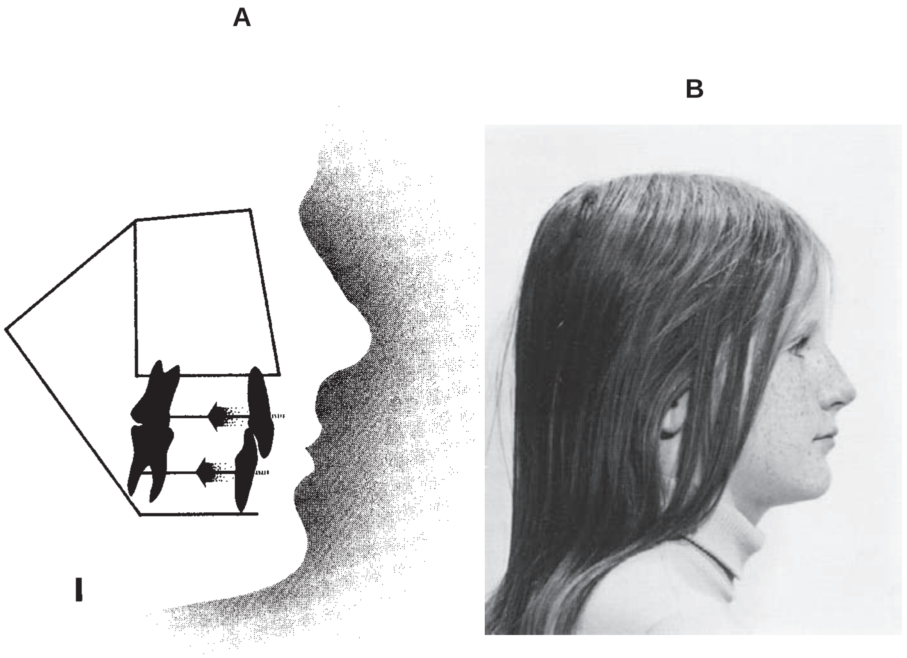


FIGURE 13-11 **A,** Class I maxillary mandibular alveolodental retrusion. **B,** Typical patient profile.

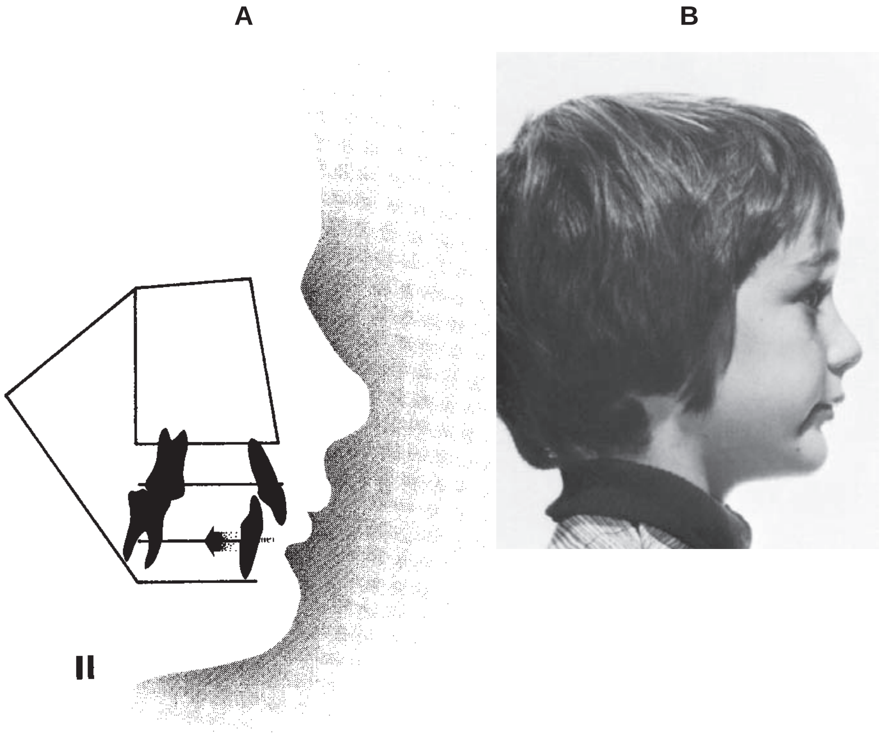


FIGURE 13-12 **A,** Class II mandibular alveolodental retrusion. **B,** Typical patient profile with adverse lip support of the malocclusion during swallowing.

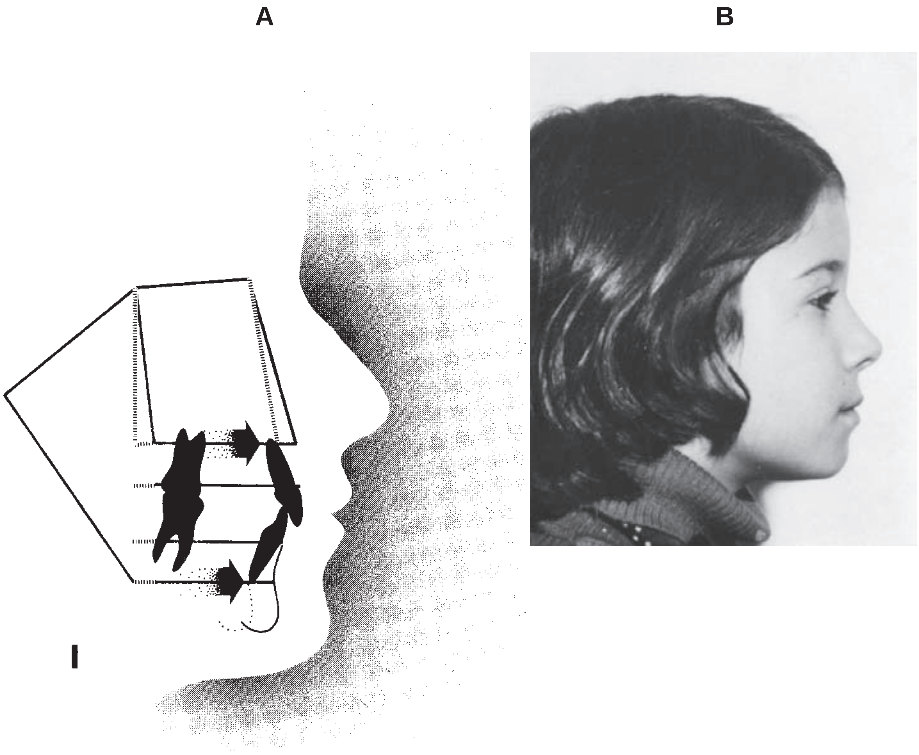


FIGURE 13-13 **A,** Class I maxillary mandibular prognathism. **B,** Typical patient profile.

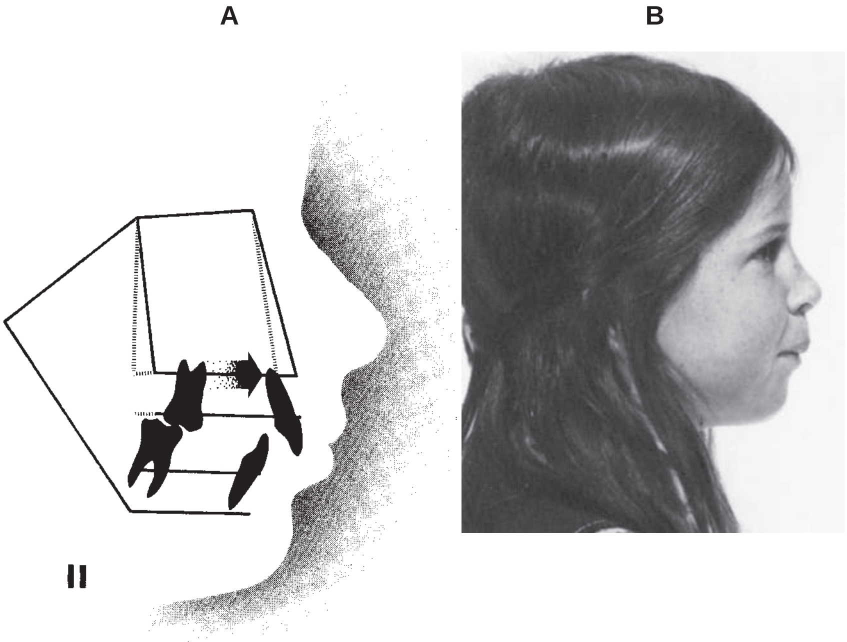


FIGURE 13-14 **A,** Class II maxillary prognathism. **B,** Typical patient profile.

High Angle (Hyperdivergent). The hyperdivergent facial pattern includes a steep mandibular plane and usually is associated with a prognathic maxilla; a retrognathic mandible; a maxillary mandibular alveolodental protrusion; an open-bite relationship of the incisor teeth; an incompetent lip relationship; a long, sloping forehead with a heavy glabella and supraorbital rims; a nose that is long and thin; and a flattened recessive chin exhibiting muscle tension (Figure 13-18).

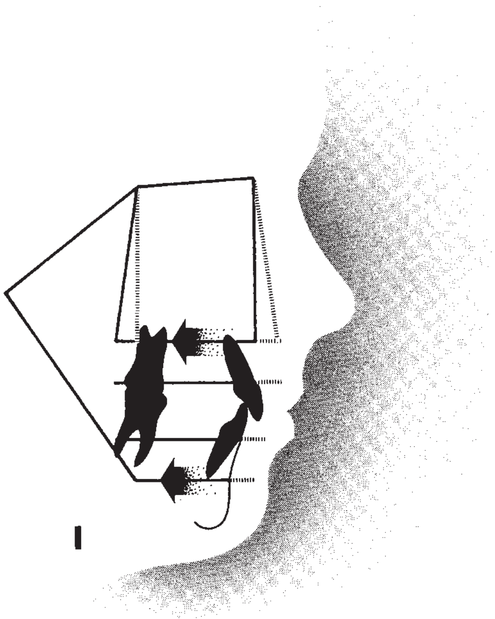


FIGURE 13-15 Class I maxillary mandibular retrognathism.

Cephalometrically, the mandibular plane to S-N angle is greater than 32 degrees in the Steiner analysis. The Frankfurt mandibular plane angle (FMA) is greater than 25 degrees in the Tweed analysis. Additional features include dolichocephalic head form, leptoprosopic facial form, large gonial angle, short ramus, small coronoid process, antegonial notching, long anterior face height, short posterior face height, long lower face height relative to upper face height, large cranial base angle (which is responsible for a downward and forward position of the nasomaxillary complex), and a downward and backward position of the mandible. This pattern in turn contributes to a steep occlusal plane and frequently to an exaggerated curve of occlusion. The following are characteristic: microgenia, narrow and long symphysis, high and narrow palate, tooth-size/jaw-size discrepancy caused by large teeth, impacted third molars, small interincisal angle, overerupted incisors despite an open-bite tendency, convex soft tissue profile, weak temporal muscles, restricted pharyngeal space with the tongue forward, mouth breathing, narrow nasal apertures, vertical mandibular growth, and ectomorphic body type with slow skeletal development and poor posture. The extraction of teeth is routinely part of the orthodontic treatment plan in these facial patterns. Extraction is necessary to relieve crowding, assist in the correction of the open-bite tendency, and position the mandibular incisors upright. If not too severe, serial extraction may be permissible.

Low Angle (Hypodivergent) The low-angle facial pattern routinely exhibits a low mandibular plane angle accompanied by a favorable horizontal skeletal

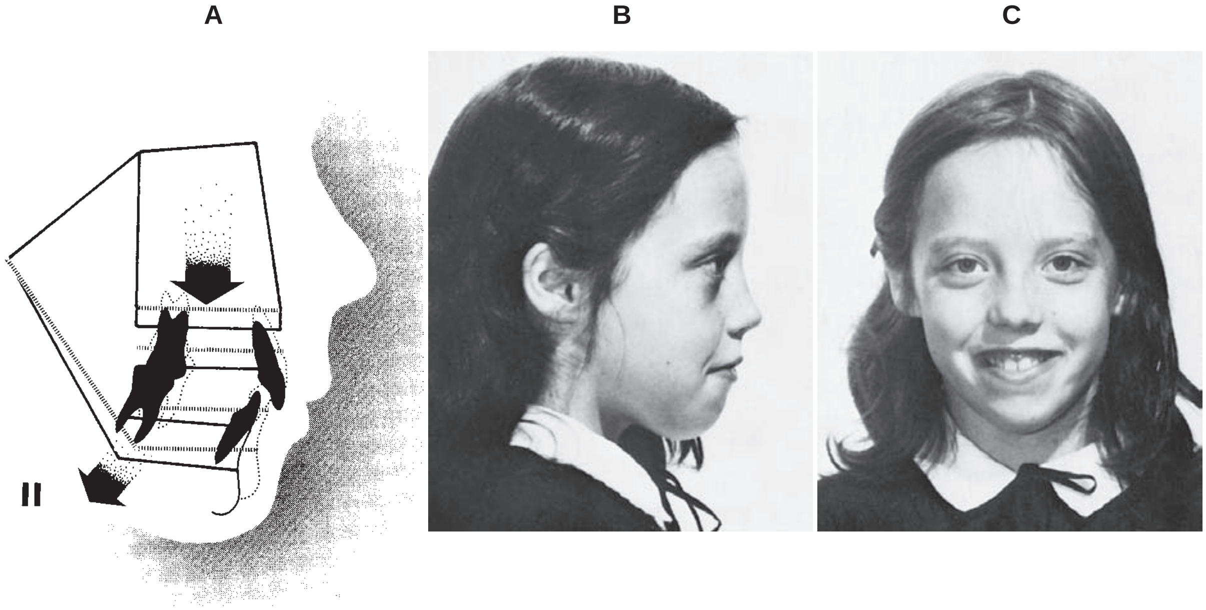


FIGURE 13-16 **A,** Class II mandibular retrognathism with increased vertical facial height. **B, C,** Typical patient profile and frontal view. Patients with excessive vertical development reveal substantial gingival tissue when smiling.

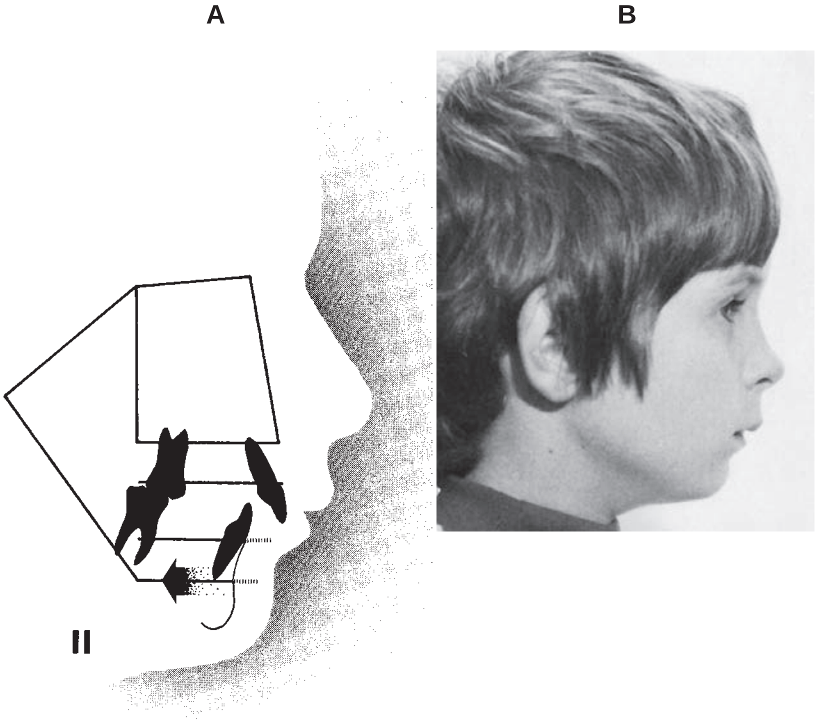


FIGURE 13-17 **A,** Class II mandibular retrognathism. **B,** Typical patient profile.

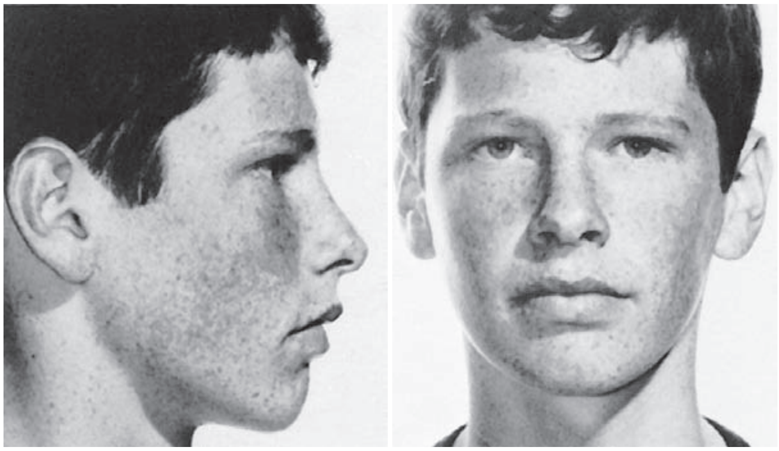


FIGURE 13-18 High-angle facial pattern. Facial planes are divergent. Chin profile projection is weak.

relationship or an orthognathic facial pattern, maxillary mandibular alveolodental retrusion, deep overbite relationship of the incisor teeth, prominent chin, straight or dished-in soft tissue profile, and a shorter nose (Figure 13-19).

Cephalometrically the mandibular plane to S-N is less than 32 degrees in the Steiner analysis. The FMA is less than 25 degrees in the Tweed analysis. Additional features include a broad brachycephalic head form, a euryprosopic facial form, wide-set eyes, prominent cheek bones, bulbous forehead, less prominent glabella and supraorbital ridges, small gonial angle, broad and long ramus, large coronoid processes, and no antegonial notching on the lower border of the mandible. The anterior face height equals the posterior face height. Compared with the upper face height, the lower face height is small. A small cranial base angle is responsible for an upward and backward position of the nasomaxillary complex and an upward and forward position of the mandible. Macrogenia is common. The palatal vault is flat with a wide dental arch and potentially small teeth. The mandibular incisors may be crowded as a result of a deep overbite, or spaced dentition may result. More abrasion of teeth occurs, along with early formation and eruption of teeth; thin lips; deep mentalis sulcus; heavy masseter muscles, with vertical pull; strong temporal

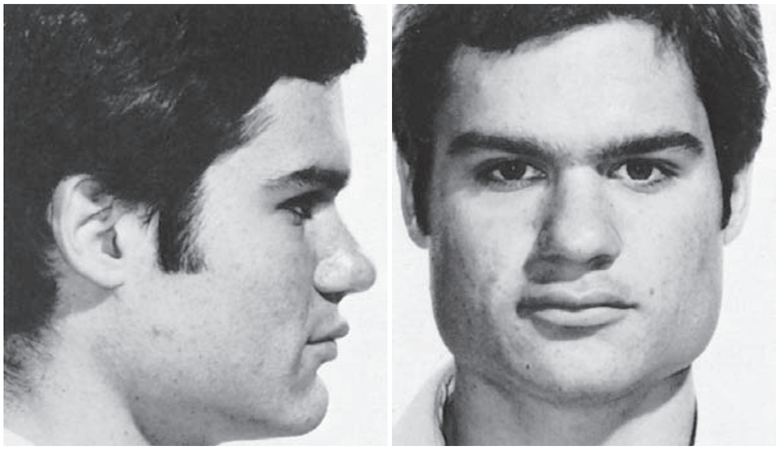


FIGURE 13-19 Low-angle facial pattern. Facial planes are convergent. Chin profile projection is strong.

muscles; and large pharyngeal space, with a posterior tongue position. Less tongue thrusting occurs when swallowing with low-angle facial patterns. The nasal apertures are large. The mandibular growth is horizontal. The body is endomorphic with advanced skeletal age and upright posture. These patients have less need for extraction, indeed every effort is made to avoid the extraction of teeth. Arch length can be gained by correcting the deep overbite and positioning the mandibular teeth upright. Serial extraction, in most instances, is contraindicated.

The Teeth

According to the Burlington Orthodontic Research Project,[17] 34% of 3-year-old children enjoy a normal occlusion. By the time they reach 12 years of age, only 11% have a normal intercuspation—a reduction of 23%. Local environmental factors are largely responsible. For example, crowded dentition results from a loss of arch length caused by the premature loss of primary teeth.

Serial extraction is an interceptive procedure designed to assist in the correction of hereditary tooth-size/jaw-size discrepancies. Because the malocclusions of 66% of 3-year-old children are hereditary (with a significant number of tooth-size/jaw-size discrepancies), serial extraction is an invaluable adjunct to interceptive treatment. This is especially true in the case of Class I malocclusions and to a lesser extent in the Class II malocclusions.

Class I malocclusions are ideal for serial extraction because the dentition is basically in a favorable relationship and successful treatment is possible with a minimum of mechanotherapy.[18,19] The ideal conditions for serial extraction are (1) a true, relatively severe hereditary tooth-size/jaw-size discrepancy; (2) a mesial step mixed dentition developing into a Class I permanent relationship; (3) a minimal overjet relationship of the incisor teeth; (4) minimal overbite; and (5) a facial pattern that is orthognathic or with a slight alveolodental protrusion.

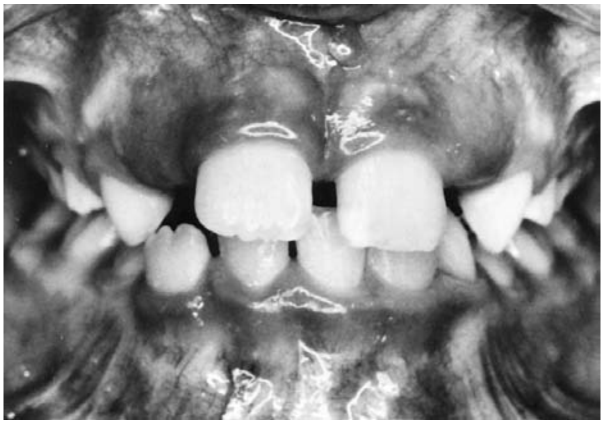


FIGURE 13-20 Premature exfoliation of one primary mandibular canine with a resulting midline discrepancy.

Clinical Analysis.

Hereditary Crowding. The signs of a true hereditary tooth-size/jaw-size discrepancy may be outlined as follows:

1. Maxillary mandibular alveolodental protrusion without interproximal spacing
2. Crowded mandibular incisor teeth
3. A midline displacement of the permanent mandibular incisors, resulting in the premature exfoliation of the primary canine on the crowded side (Figure 13-20)
4. A midline displacement of the permanent mandibular incisors with the lateral incisors on the crowded side blocked out, usually lingually (Figure 13-21) but occasionally labially
5. A crescent area of external resorption on the mesial aspect of the roots of the primary canines caused by crowded permanent lateral incisors

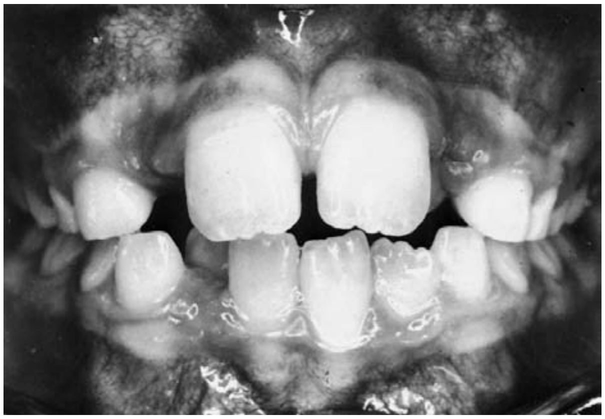


FIGURE 13-21 One permanent mandibular lateral incisor blocked out lingually with a midline discrepancy.

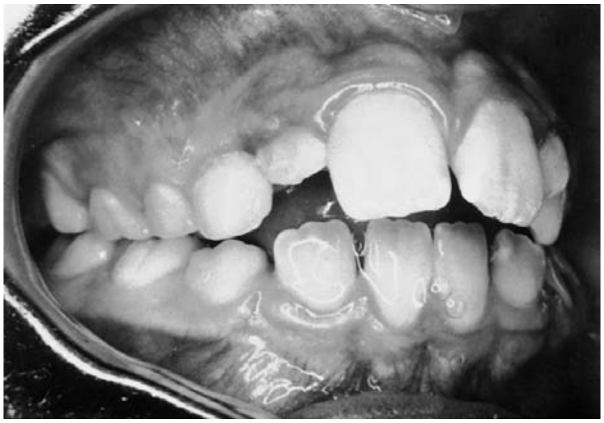


FIGURE 13-22 Bilateral exfoliation of primary mandibular canines resulting in an increase in overjet, with uprighting of lower incisors.

6. Bilateral primary mandibular canine exfoliation, resulting in an upright positioning of the permanent mandibular incisors; this in turn increases overjet (Figure 13-22) and/or the overbite as lower incisors retract
7. A splaying out of the permanent maxillary or mandibular incisor teeth caused by the crowded position of the unerupted canines (Figure 13-23)
8. Gingival recession on the labial surface of the prominent mandibular incisor
9. A prominent bulging in the maxilla or mandible caused by the crowding of the canines in the unerupted position
10. A discrepancy in the size of the primary and permanent teeth, reducing the leeway space
11. Ectopic eruption of the permanent maxillary first molars, resulting in the premature exfoliation of the primary second molars, which indicates a lack of development in the tuberosity area (see Figure 13-36)
12. A vertical palisading of the permanent maxillary first, second, and third molars in the tuberosity area, again indicating a lack of jaw development (Figure 13-24)

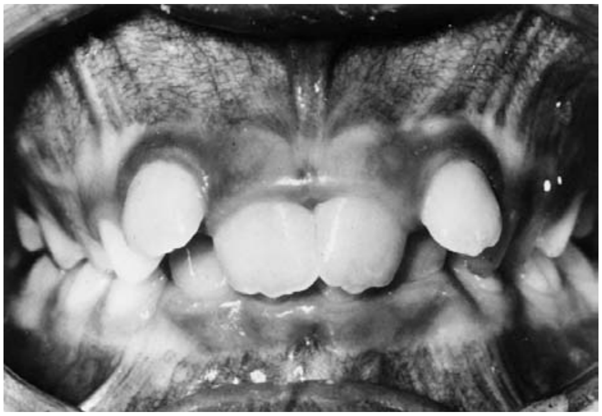


FIGURE 13-23 Splayed maxillary lateral incisors. This is often coupled with mesial eruption of the permanent maxillary cuspids with potential for damage to the lateral incisor roots if appliances are placed.

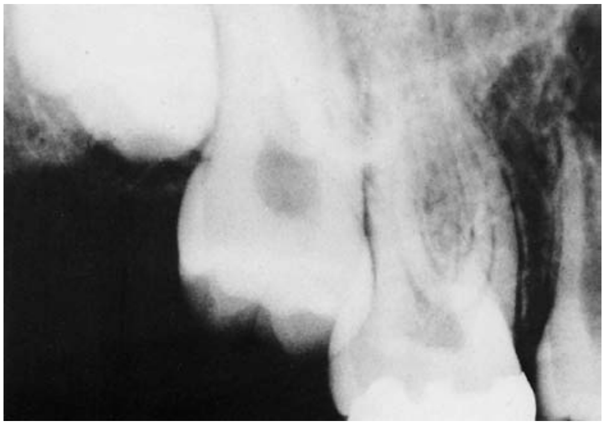


FIGURE 13-24 Palisading of the maxillary molars. The clinician should monitor for impaction of the second molars with potential need early third molar removal.

13. Impaction of the permanent mandibular second molars in the absence of treatment

True hereditary tooth-size/jaw-size discrepancies must be differentiated from crowded dentitions resulting from factors that are more environmental in nature. True hereditary crowding likely will be treated with the aid of extractions and, if discovered early, with serial extraction. However, crowding resulting from environmental factors may be treated without extractions.

Environmental Crowding. Environmental crowding may result under the following conditions:

1. Trauma that affects surrounding hard and soft tissues
2. Iatrogenic malocclusion due to ill-conceived space management
3. Discrepancy in the size of individual teeth (Figure 13-25)

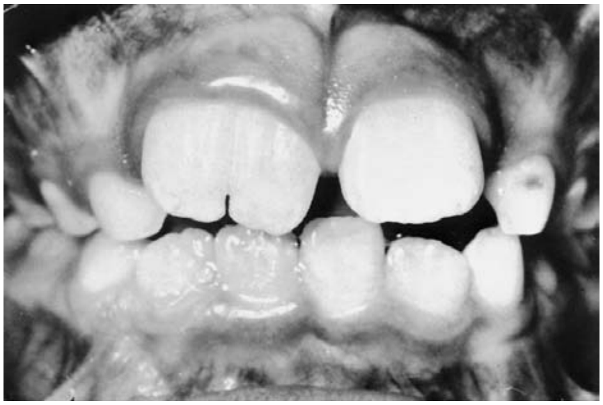


FIGURE 13-25 Discrepancy in the size of individual teeth.

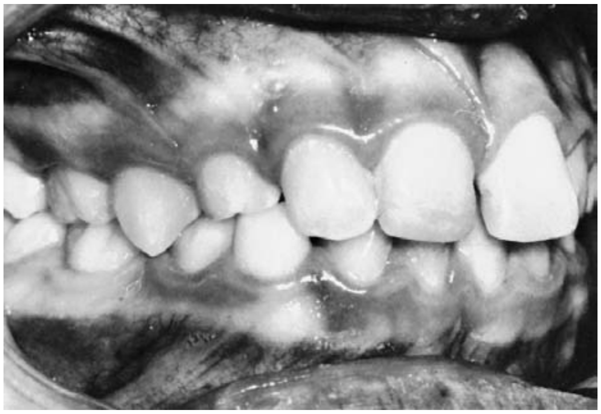


FIGURE 13-26 Maxillary canine erupted in the premolar position. This may be related to a transposed canine and ectopic premolar or an absent premolar.

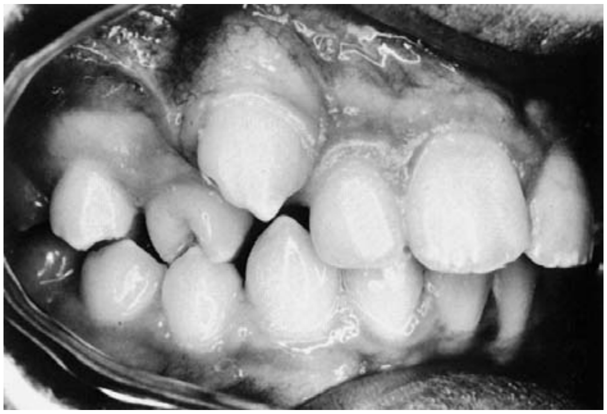


FIGURE 13-27 Rotated maxillary premolar consuming more space than it would in its normal position.

4. Discrepancy between mandibular tooth size and maxillary tooth size
5. Aberration in the shape of teeth, i.e., extra cusps
6. Aberration in the eruptive pattern of the permanent teeth (Figure 13-26)
7. Transposition of teeth (see Figure 13-38)
8. Uneven resorption of primary teeth
9. Rotation of premolar teeth causing loss of space for erupting canines (Figure 13-27)
10. Ankylosis of primary teeth, most often in first and second primary molars, with adjacent tooth tipping
11. Reduction of arch length caused by interproximal caries in the primary teeth (see later Figure 13-33)
12. Premature loss of primary teeth resulting in a reduction of arch length from subsequent drifting of permanent teeth (see later Figures 13-34 to 13-37, *A*)
13. Altered emergence sequence (see later Figure 13-43)
14. Exfoliation sequence of primary teeth (see later Figure 13-37, *A*)
15. Prolonged retention of primary teeth

Because serial extraction is performed during the mixed-dentition period, careful examination of the transformation from the primary to the permanent dentition is of utmost importance. A thorough understanding of the eruption sequence and range of timing in tooth eruption is critical. One of the most important daily aspects in mixed-dentition patient evaluation is the observation of the tooth eruption pattern and follow-up on alterations in the patient's sequence of eruption. While there are many permutations on "normal," intercepting individual, specific developing problems results in reduced needs for mechanotherapy.

Dental Development in the Mixed Dentition. At present, overwhelming scientific evidence indicates that the posterior teeth move forward throughout life. This tends to reduce arch length. Moorrees[20] has established that arch length decreases 2 to 3 mm between 10 and 14 years, when the primary molars are being replaced by the permanent premolars (Figure 13-28). He also has demonstrated that the arch circumference is reduced about 3.5 mm in the mandible of boys and 4.5 mm in girls during the mixed-dentition period.

DeKock[21] measured a 10% decrease in arch length for males and 9% for females over a period of 10 years beyond the period of the mixed dentition, from 12 years to 26 years (Figure 13-29). Brodie[22] has observed that in newborn infants the tongue tends to fill the oral cavity and often encroaches on the alveolar ridge area. As a consequence of the more rapid anterior growth of the jaws in the postnatal period, the tongue lags behind and comes to occupy a more posterior position in the oral cavity. This is consistent with the upright positioning of the incisors that occurs in many adolescents as noted by Enlow,[23] Bjork[24] (Figure 13-30), Tweed,[11] and others.

These findings suggest that as facial growth continues in an anterior direction into adulthood, it thrusts the mandible into the facial musculature, which produces a posterior force vector on the crowns of the incisors. Thus arch length decreases from the anterior and the posterior side. To repeat, serial extraction is based on the fact that arch length does not increase. If crowding is evident at

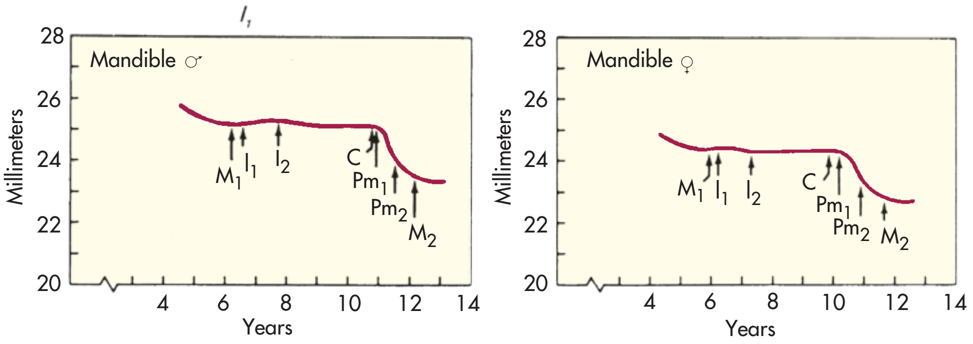


FIGURE 13-28 Reduction in arch length as a result of the moving forward of posterior teeth. *(From Moorrees CF, Reed RB: Changes in dental arch dimension expressed on the basis of tooth eruption as a measure of biologic age,* J Dent Res *44:129, 1965.)*

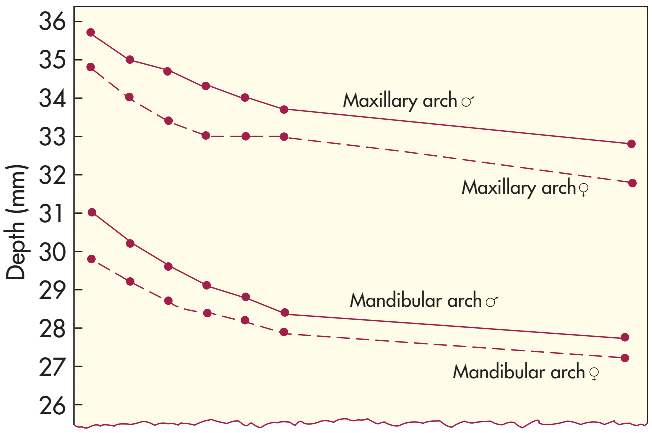


FIGURE 13-29 Reduction in arch depth. *(From DeKock WH: Dental arch depth and width studies longitudinally from 12 years of age to adulthood,* Am J Orthod *62:56, 1972.)*

8 years, it will not improve with further growth and development.

First molars Several situations can exist for the permanent first molars. In patients with a spaced primary dentition and a straight terminal plane relationship of the primary molars, the permanent mandibular first molars emerge at about 6 years, move the primary molars mesially, close the space distal to the primary canines, convert the straight terminal plane to a mesial step relationship, reduce arch length in the mandibular dentition, and allow the permanent maxillary molars to emerge into a Class I relationship. This has been referred to as the early mesial shift (Figure 13-31).

In patients with a closed primary dentition and a straight terminal plane, the permanent maxillary and mandibular first molars emerge into a cusp-to-cusp relationship simply because no spaces exist. At about 11 years, the primary mandibular second molars are exfoliated, and the permanent mandibular first molars migrate mesially into the excess leeway space provided by the differences in mesiodistal dimensions of the primary second molars and the permanent second premolar teeth.

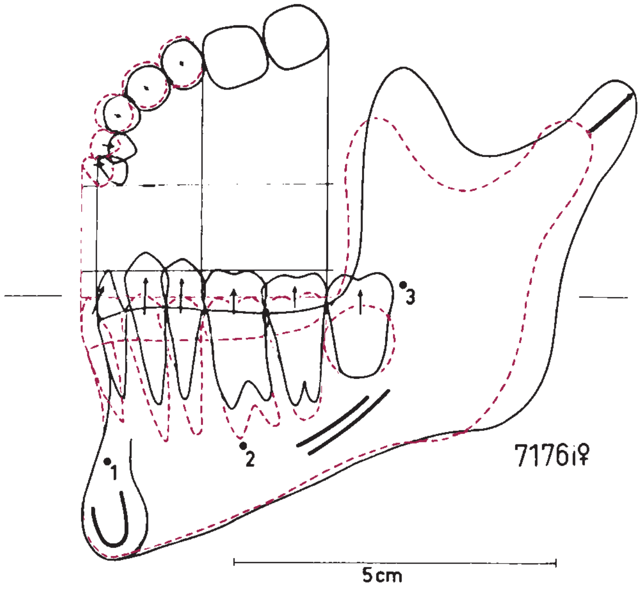


FIGURE 13-30 Upright positioning of incisors with forward growth. *(From Bjork A: Variations in the growth pattern of the human mandible: longitudinal radiographic study by the implant method,* J Dent Res *42:400, 1963.)*

Again, this reduces arch length, converts the straight terminal plane to a mesial step, and provides for a Class I relationship of the permanent first molars. This shift has been referred to as the late mesial shift (Figures 13-28 and 13-32). If the permanent maxillary first molars emerge before the mandibular molars, just the reverse of the early mesial shift—an abnormal Class II relationship—will occur and a reduction in the maxillary arch length will result.

If extensive interproximal caries is allowed to develop in the maxilla, a similar situation will occur: a reduction of arch length causing crowding (Figure 13-33). If the caries is so extensive that extraction of the primary maxillary second molars is necessary, again, crowding will result (Figure 13-34). Similarly, and this is contrary to

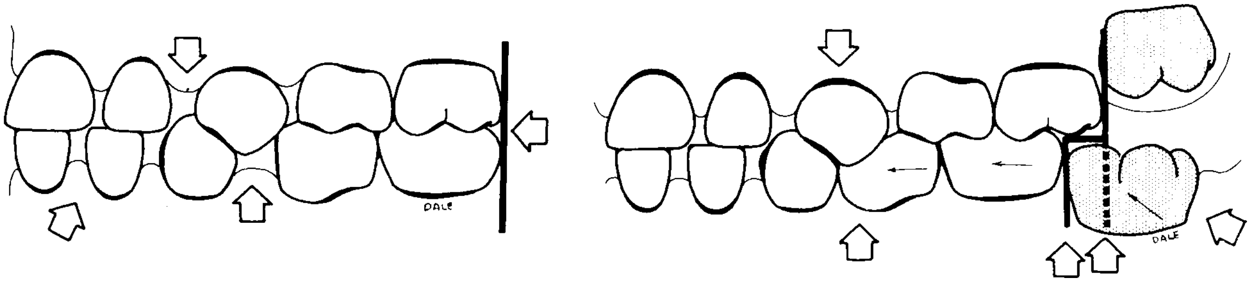


FIGURE 13-31 Early mesial shift. Note the use of normal developmental spaces in the mixed dentition to bias the occlusal development for a mesial shift of the mandibular teeth versus the maxillary teeth.*

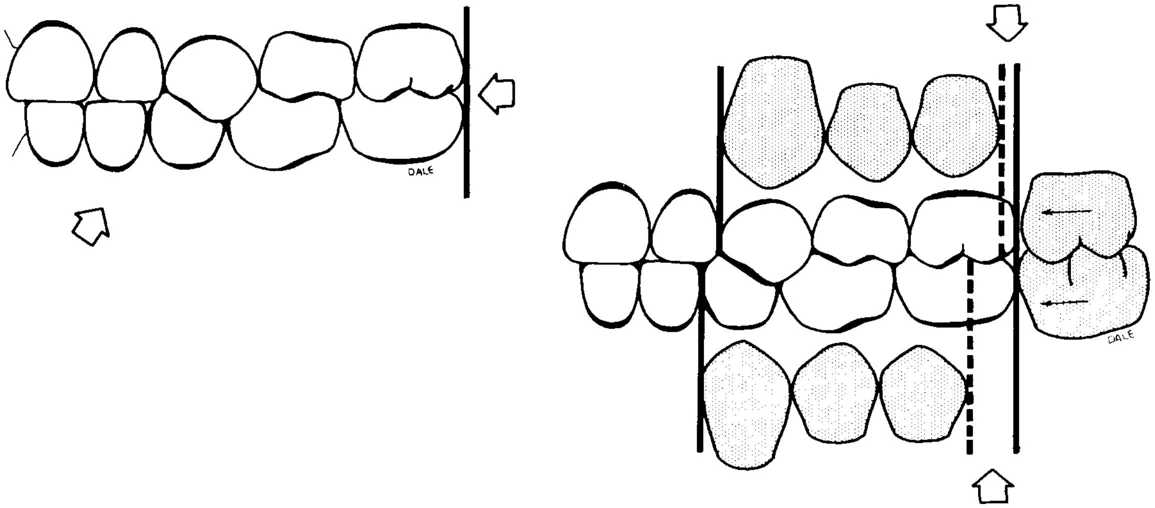


FIGURE 13-32 Late mesial shift. This pattern is seen where there is minimal developmental spacing in the primary and early mixed dentition.*

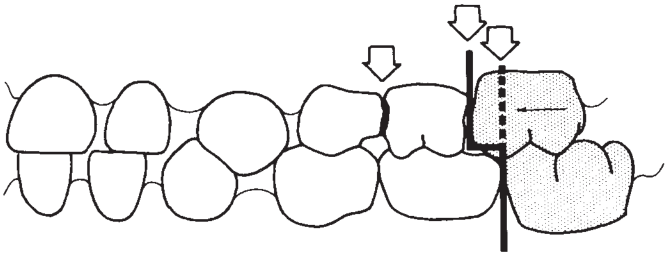


FIGURE 13-33 Reduction in arch length as a result of caries.

popular belief, premature loss of the primary maxillary first molars will cause crowding (Figure 13-35).

Ectopic eruption of the permanent maxillary first molars, resulting in premature exfoliation of the primary second molars and loss of arch length, indicates a lack of development of the tuberosity. This results in not only crowding but also a Class II molar relationship (Figure 13-36).

If the exfoliation sequence of the primary second molars is reversed and the maxillary molar is lost before the mandibular, a Class II relationship of the permanent first molars will result. Again, arch length will be reduced, and crowding will occur in the maxilla (Figure 13-37, *A*).

However, if the primary mandibular second molar is lost far too early, the mandibular arch length will be reduced to such an extent that the normal leeway will be exceeded and crowding will occur (Figure 13-37, *B*).

The normal leeway, according to Lo and Moyers,[25] is 2.6 mm (1.3 mm on each side) in the maxilla and 6.2 mm (3.1 mm on each side) in the mandible. However, this leeway varies considerably and should be measured on each patient. For a discrepancy to exist between the size of the primary teeth and the size of the permanent teeth to such an extent that no positive leeway is available is possible. A negative leeway may exist. According teeth to Horowitz and Hixon,[26] correlations in size between a single primary tooth and its successor range from $r = 0.2$ to $r = 0.6$. This means that anywhere from 4% to 36% of the successors are favorably correlated in size to the primary teeth. In other words, if the primary tooth is small, its successor will be small. According to Arita and Iwagaki,[27] Hixon and Oldfather,[28] Lewis and Lehman,[29]

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*Adapted from Baume LJ: Physiological tooth migration and its significance for the development of occlusion. II. The biogenesis of the accessional dentition, J Dent Res 29:331, 1950.

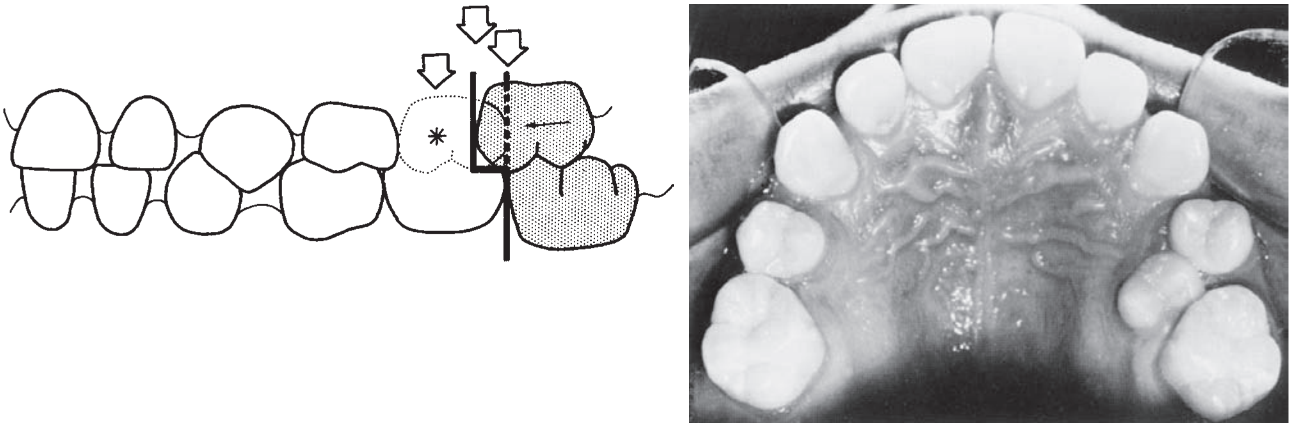


FIGURE 13-34 Reduction in arch length as a result of premature loss of primary maxillary second molars.

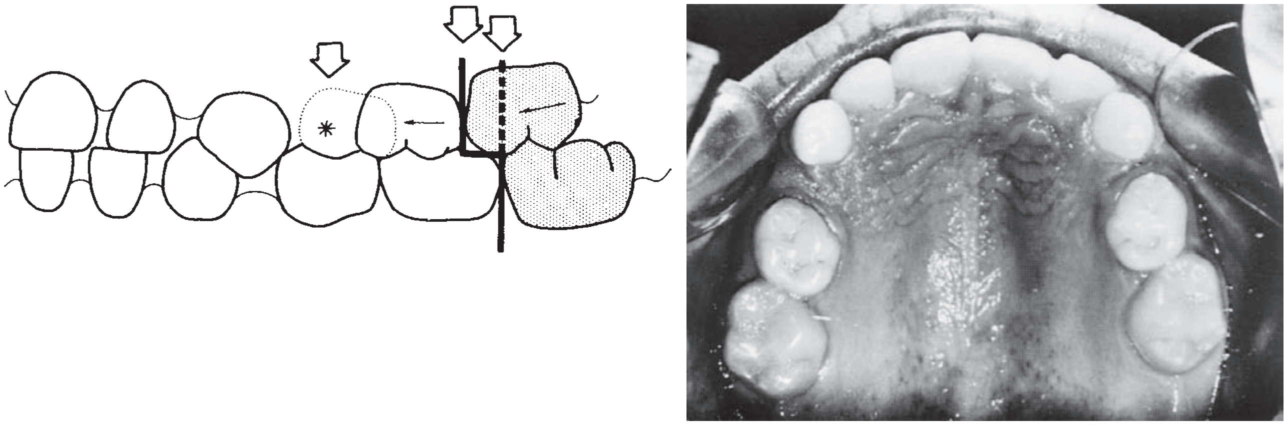


FIGURE 13-35 Reduction in arch length as a result of premature loss of the primary maxillary first molars.

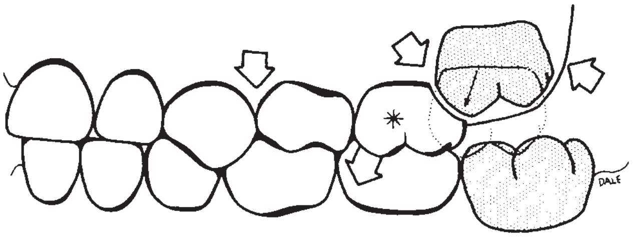


FIGURE 13-36 Reduction in arch length as a result of ectopic eruption of the permanent maxillary first molars.

Moorrees and Chadha,[30] and Moorrees et al.,[31] the size correlation between all the primary teeth and their successors is approximately $r = 0.5$. Therefore 25% of the time a positive relationship exists. That is not too favorable for optimal occlusion.

Incisors. Several situations can exist also for the incisors. Ideally, the primary spacing of the spaced primary dentition will be sufficient, together with other factors, to allow for the accommodation and favorable alignment of the succedaneous permanent incisors (Figure 13-38).

In primary dentitions where there is no interdental spacing, the permanent mandibular lateral incisors emerge and the primary mandibular canines are moved laterally. Thus a space is created that enables the permanent maxillary lateral incisors to emerge into a favorable alignment. This is referred to as *secondary spacing* and was first described by Baume (Figure 13-39).[32] Secondary spacing also occurs when the permanent mandibular central incisors are emerging.

Both of these observations have been substantiated by the findings of Moorrees[20] that show an increase in intercanine width during the period of incisor emergence (Figure 13-40). Moorrees also has demonstrated an increase in arch circumference in the maxilla of boys of 1.5 mm and of girls of 0.5 mm during this period of development.[33]

If the primary canines are reduced in size or extracted when this natural phenomenon is occurring, an increase in intercanine distance and secondary spacing may not occur. Thus borderline discrepancies may be converted from a nonextraction treatment to extraction.

Research conducted by Moorrees and Chadha[34] has revealed an increase in the crowding of maxillary and mandibular incisors when they are emerging into the oral cavity. However, 2 mm of crowding in the incisor segment in the mandible of boys will recover to no crowding by 8 years on the average. Girls recover to about 1 mm of crowding. The maxillary dentitions of boys and girls do not exhibit the same tendency to crowding. However, during the eruption of the incisors, 2 to 3 mm of spacing is reduced to 0 (Figure 13-41). This is a significant finding because it tells the clinician not to be alarmed with a slight amount of crowding in the early stages of emergence of the permanent incisors. The reduction in size, or extraction, of the primary canines should be deferred. In fact, the patient may not require extraction at all.

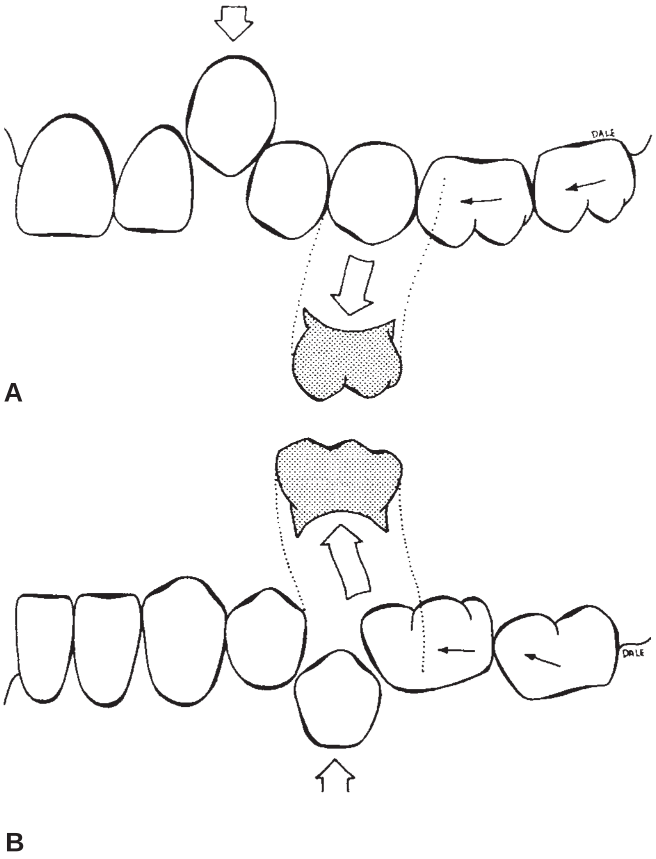


FIGURE 13-37 **A,** Reduction in arch length as a result of premature exfoliation of the primary maxillary second molar. **B,** Reduction in arch length as a result of premature loss of the primary maxillary or mandibular second molar.

Intercanine distance increases more in the maxilla and in closed dentitions, which lack primary tooth interdental spaces. A true hereditary tooth-size/jaw-size discrepancy is characterized by an ectopic eruption of the permanent mandibular lateral incisors and a premature exfoliation of the primary canines (Figure 13-42).

Warren Mayne[35] described a concept he termed *incisor liability*. In his discussion, he outlined the way in which incisor liability could be used clinically to determine anterior crowding. He described the following principal variables:

1. The four permanent maxillary incisor teeth are, on the average, 7.6 mm larger than the primary incisors.[36] The four permanent mandibular incisors are 6.0 mm larger. This size differential is the incisor liability. The liability varies greatly from individual to individual, and for this reason the patient's own tooth measurements should be used in the analysis. A favorable incisor liability exists when the spacing of the primary anterior teeth is sufficient to allow for the eruption of the permanent incisors without any crowding (see Figure 13-38).
2. A more precarious incisor liability situation exists when no primary spacing is present in a closed primary dentition. Then the individual must rely on the development of secondary spacing to create sufficient space for the permanent incisors to emerge without crowding (see Figure 13-39).
3. An impossible situation exists when the incisor liability is of such magnitude that growth and development will never be able to meet the space demands required by the permanent incisors. Such patients are doomed

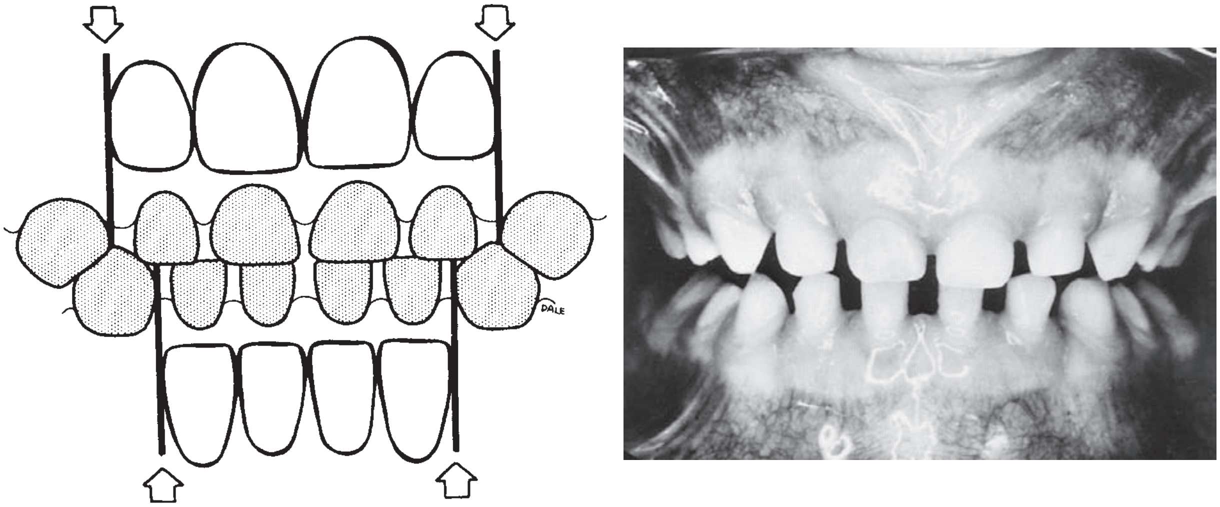


FIGURE 13-38 Primary spacing. Allows larger incisors to erupt with reduced chance of crowding.

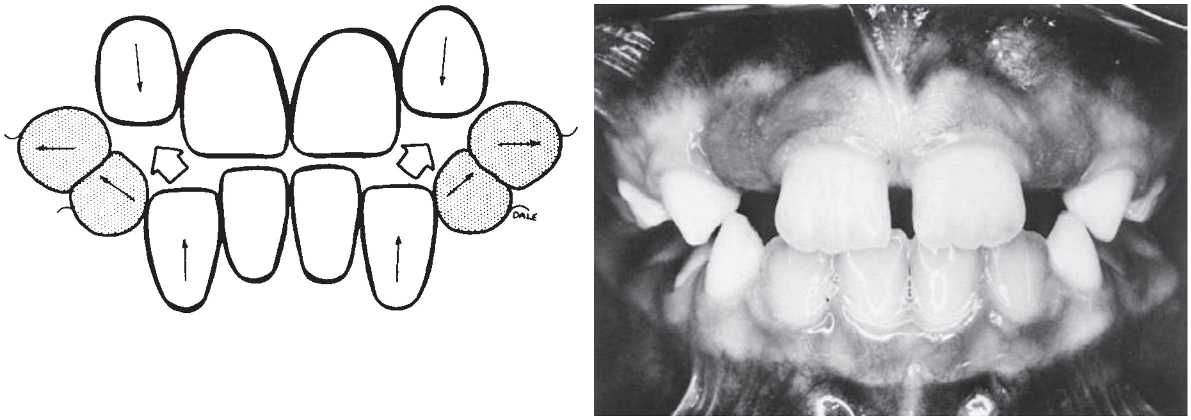


FIGURE 13-39 Secondary spacing occurring when the permanent mandibular lateral incisors are emerging.

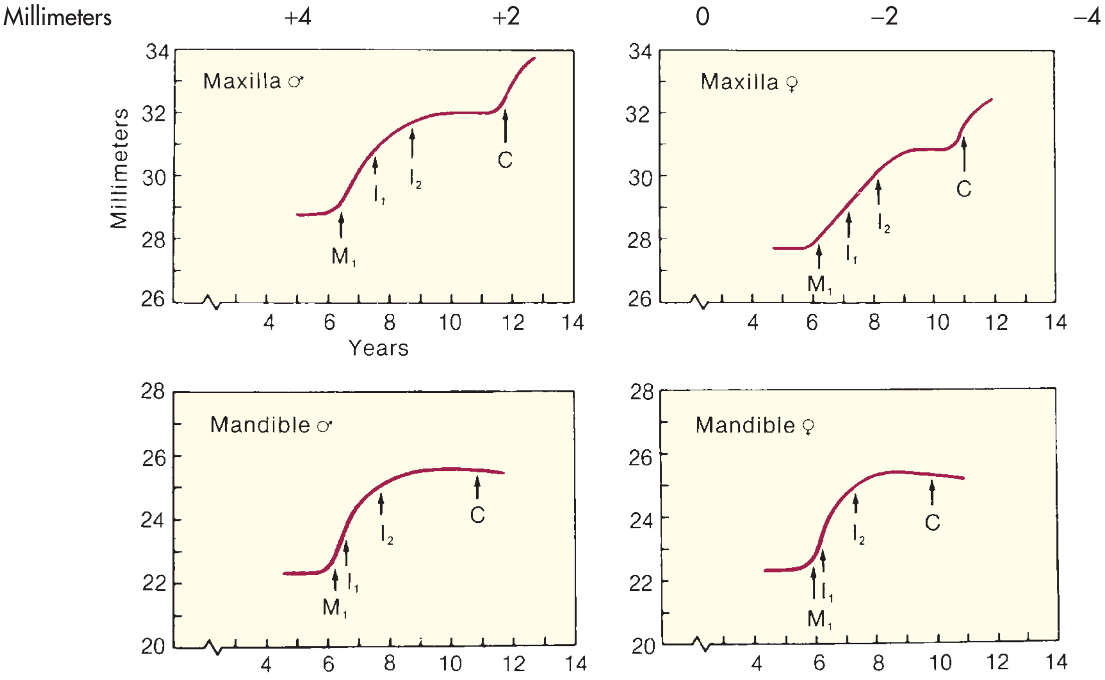


FIGURE 13-40 Average intercanine distance. *(From Moorrees CF, Reed RB: Changes in dental arch dimension expressed on the basis of tooth eruption as a measure of biologic age,* J Dent Res *44:129, 1965.)*

to severe crowding and irregularity from the outset (see Figure 13-42).

4. In the primary dentition the interdental spacing may range between 0 and 10 mm in the maxilla, with an average of 4 mm, and between 0 to 6 mm in the mandible, with a range of 3 mm.
5. During the period of permanent incisor eruption, notable amounts of intercanine arch width development occur in the maxillary and mandibular dentition. In the mandible the increase occurs between 6 and 9 years for boys and between 6 and 8 years for girls. In the maxilla it increases longer, to 16 years in boys and 12 years in girls (see Figure 13-40).
6. After 10 years of age little intercanine arch width change is expected in the mandible of boys or girls. The average increase in the mandibular dentition of boys and girls is about 3 mm; in the maxilla it is about 4.5 mm (see Figure 13-40).
7. The permanent incisor teeth erupt slightly labial to the arch position of the primary incisors and for a time at least are more procumbent.[35]

Incisor crowding may be assessed by using the variables just described. First, a favorable situation, described previously, exists when sufficient primary spacing is present in the spaced primary dentition to allow for the eruption of the permanent incisors without crowding (Table 13-1; see also Figure 13-38).

Second, a precarious situation exists with a primary dentition with no anterior developmental spaces. A substantial increase in intercanine width is necessary to provide secondary spacing so that the permanent incisors

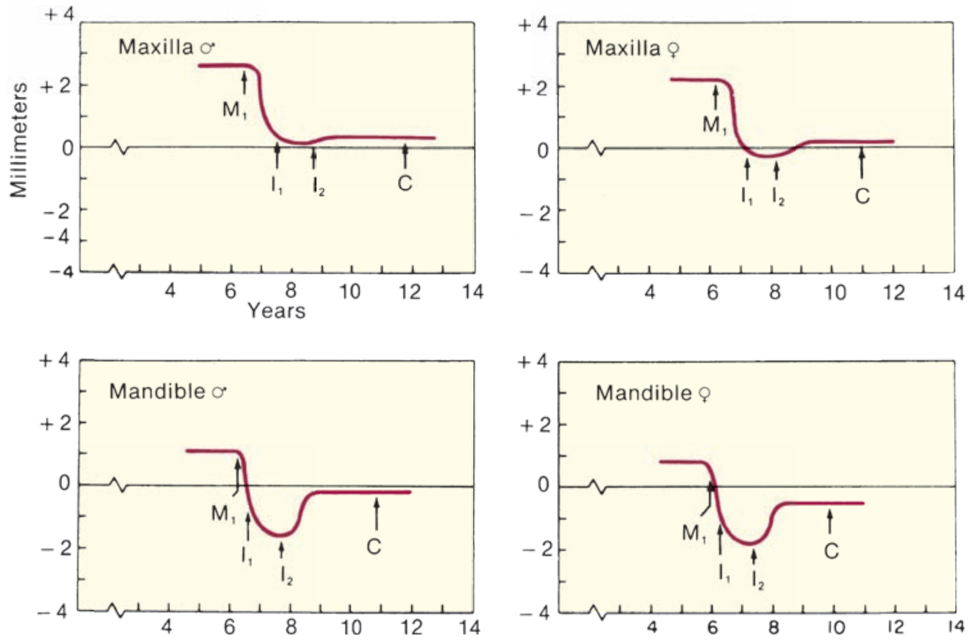


FIGURE 13-41 Available space in the incisor segment. *(From Moorrees CF, Chadha IM: Available space for the incisors during dental development: A growth study based on physiological age,* Angle Orthod *33:44, 1963.)*

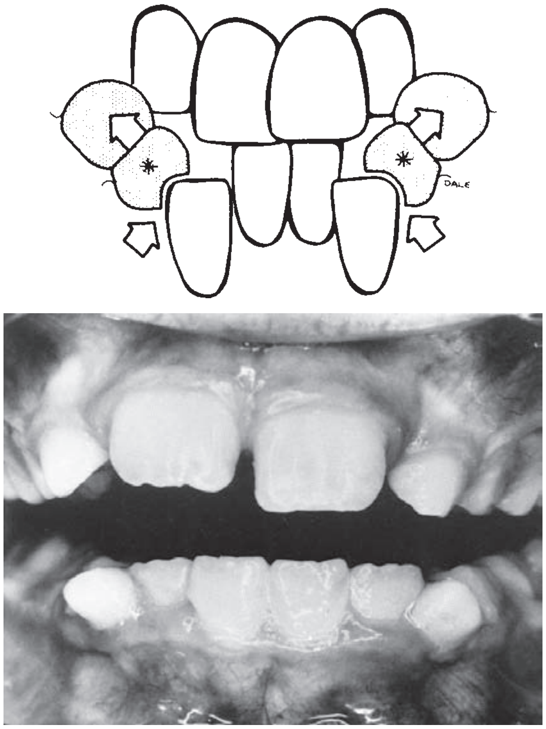


FIGURE 13-42 Ectopic eruption of the permanent mandibular lateral incisors and its effect on secondary spacing.

TABLE 13-1 Incisor Liability

Situation	Maxilla (mm)	Mandible (mm)
Favorable: Primary Spacing		
Incisor liability	−6.2	−4.3
Interdental spacing	+4.0	+3.0
Incisor position	+2.2	+1.3
—	6.2	4.3
Amount of crowding	—	—
Precarious: Secondary Spacing		
Incisor liability	−9.2	−7.3
Interdental spacing	+4.0	+3.0
Intercanine arch width	+3.0	+3.0
Incisor position	+2.2	+1.3
—	9.2	7.3
Amount of crowding	—	—
Impossible: Ectopic		
Incisor	−14.2	−12.3
Interdental spacing	+4.0	+3.0
Intercanine arch width	+3.0	+3.0
Incisor position	+2.2	+1.3
—	9.2	7.3
Amount of crowding	5.0	5.0

erupt without appreciable crowding (see Figure 13-39 and Table 13-1). In these patients the practitioner avoids interproximal reduction or extraction of primary canines.

Finally, an impossible situation exists with a true hereditary tooth-size/jaw-size discrepancy and an incisor liability that cannot be compensated by interdental spacing, an increase in intercanine arch width, or labial positioning of the permanent incisors (see Figure 13-42 and Table 13-1). Serial extraction can be beneficial for these individuals.

Canines, Premolars, and Second Molars. The most frequently occurring sequence of eruption in the maxilla is as follows: permanent first molar, central incisor, lateral incisor, first premolar, second premolar, canine, second molar. The most frequently occurring sequence in the mandible is permanent first molar, central incisor, lateral incisor, canine, first premolar, second premolar, second molar. According to Lo and Moyers[25] this combination produces the highest incidence of favorable occlusion. More girls than boys have a favorable combination.

An unfavorable sequence can produce crowding. For instance, if the second molars erupt early, they may affect the canines in the maxilla and the second premolars in the mandible (Figure 13-43). Maxillary second molars erupt ahead of mandibular molars in 89.11% of Class II patients, whereas in only 56.5% do maxillary first molars erupt ahead of their mandibular counterparts.[25] Therefore, second molars are more important than first molars in the development of a Class II relationship.

Early exfoliation of primary teeth can disrupt the alignment of the dentition, reducing arch length in the maxilla (see Figures 13-34, 13-35, and 13-37) and mandible (see Figure 13-37, *B*).

Prolonged retention of primary teeth can cause crowding of the permanent teeth in the maxilla (Figure 13-44) or mandible (Figure 13-45).

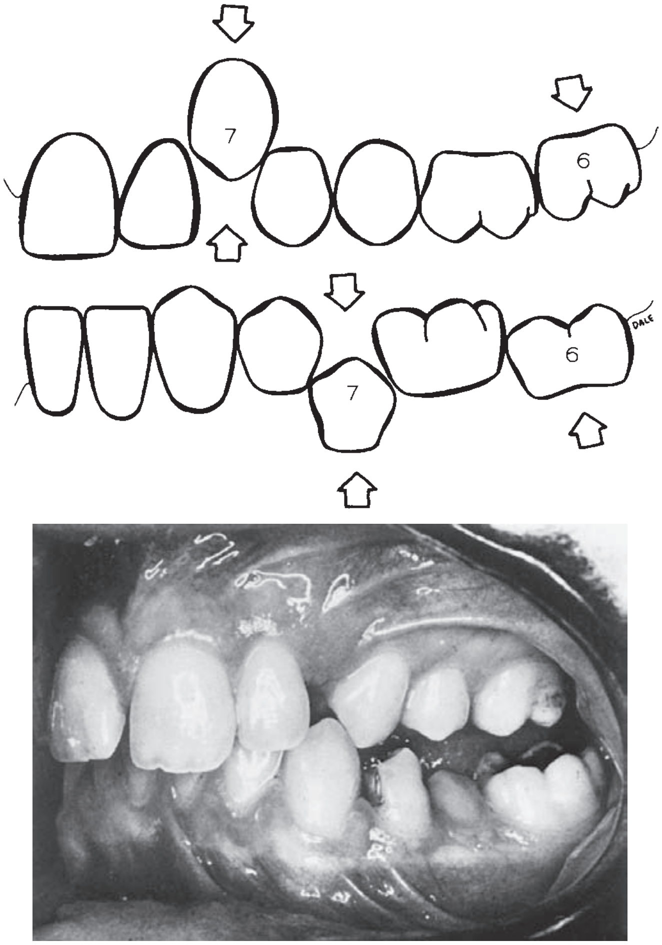


FIGURE 13-43 Unfavorable emergence sequence. The permanent second molars are emerging early, blocking the maxillary canines and mandibular second premolars.

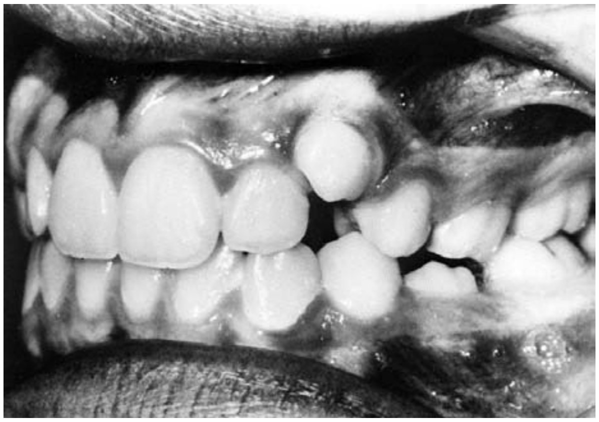


FIGURE 13-44 Prolonged retention of the primary maxillary second molar causing crowding of the permanent canine.

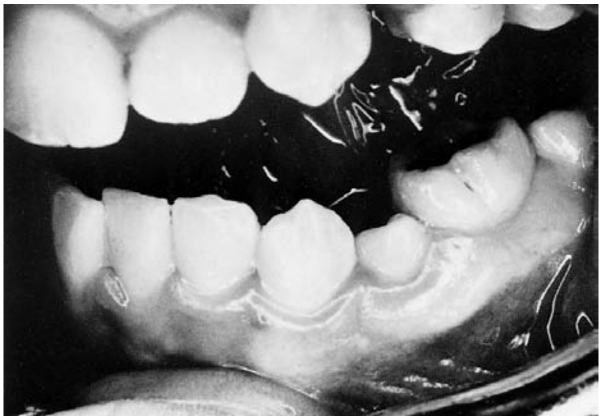


FIGURE 13-45 Prolonged retention of the mandibular second deciduous molar, causing crowding of the first premolar.

Clinically, the primary second molars appear to resist mesial migration to some extent. Rarely does the orthodontist observe primary mandibular second molars tipped mesially after the premature loss of primary first molars. However, the permanent mandibular first molars are observed to have an exaggerated mesial inclination after the premature loss of the primary second molars. The relative position of the unerupted premolars is crucial in this situation. When the primary mandibular second molars are lost prematurely, the permanent second premolars are often deep in the alveolar bone. This may encourage the permanent first molar to tip forward. When the primary mandibular first molar is lost prematurely, the permanent first premolar (which is scheduled to emerge before the second premolar) is not so deeply embedded in bone. Therefore, the tendency for tipping of the primary second molar is not as great. The unerupted first premolar tends to support the primary second molar.

Contrary to popular belief, arch length can be reduced and space can be lost after premature exfoliation or extraction of the primary first molar (see Figure 13-35). This is especially true in the mandible, where the formation of a knife-edge ridge of alveolar bone obstructs and retards the emergence of the underlying first premolar.

The premature loss of primary molars immediately leads one to consider space maintenance. However, the use of space maintainers depends on a thorough diagnosis and may be modified with subsequent treatment planning. If the patient has a normal dentition or the treatment plan does not include the extraction of permanent teeth, a space maintainer may be placed. Indeed, in the borderline situation, maintenance of the "E" space may be all that is indicated to maintain a nonextraction treatment approach.

In the maxilla, about 90% of the time the first premolar emerges ahead of the canine. This is favorable for serial extraction and maintenance of the overbite because the maxillary incisors are not held forward. About 10% of the time, the sequence is unfavorable for serial extraction and the overbite.

In the mandible, about 80% of the time the canine emerges ahead of the first premolar.[25] This eruption sequence decreases overbite because it maintains the mandibular incisors in a forward position.[37] However, the sequence is not favorable for serial extraction. About 20% of the time the sequence is favorable for serial extraction but not for maintenance of the overbite; that is, the first premolars are ahead of the canines.

Serial extraction is beneficial to prevent resorption of the roots of the maxillary lateral incisors by impacted canines. When the maxillary canine is extracted in serial extraction, the space between the lateral incisor and the primary first molar is reduced substantially. However, when the primary first molar is extracted at the proper time, the first premolar erupts, allowing the unerupted permanent canine to move away from the root of the lateral incisor. On extraction of the first premolar, the canine then erupts into place without difficulty and without danger to the lateral incisor. Certain conditions exist, which will be discussed later, under which primary first molars are extracted before the primary canines to allow the premolars to erupt. This extraction may even be done, in the presence of concern, in nonextraction malocclusions. To their knowledge, the authors have not had a lateral incisor root resorbed by an impacted canine in 33 years of practice using serial extraction procedures.

Total Space Analysis

The mixed-dentition analyses historically were dentally oriented. Unfortunately, even today, tooth-size/jaw-size discrepancies diagnosed in the mixed-dentition period still are evaluated by dental-oriented analyses. These analyses will be referred to as conventional methods. Their aim is to evaluate, as accurately as possible, future crowding in the permanent dentition using a prediction of the mesiodistal width of the permanent mandibular canines and premolars. The value obtained is added to the already known measurement of the permanent mandibular incisors. This represents space required. The space required is subtracted from the arch circumference of space available. If the result is significantly negative, future crowding can be predicted.

Tweed,[38] studying the relationship between the mandibular incisors and the mandibular plane, found that if the teeth are not in a stable relationship with the basal bone after treatment, the result may relapse. In view of this, the dental-oriented mixed-dentition analysis alone is not adequate. A facial-oriented analysis, incorporating the relations of the incisor teeth to the basal bone, is preferable. This analysis will be described as the Tweed method.

Furthermore, the various mixed-dentition analyses demonstrate the discrepancy only and do not indicate the exact area where the discrepancy occurs. In many instances the problem is confined to one specific area. Because one can direct treatment specifically to one area, knowledge of the area affected is desirable. The total space analysis provides this precise information.[39]

Garcia-Hernandez and Dale[40] completed a study of 60 Class I mixed-dentition patients in the authors' practice. One objective was to compare the conventional method, the Tweed method, and the total space analysis method in the diagnosis of tooth-size/jaw-size discrepancies before serial extraction. Sixty individuals (30 boys and 30 girls) with a mean chronologic age of 8 years 4 months (range of 7 years 7 months to 11 years 3 months) were selected from the records of the practice.

Conventional Method. The "conventional" calculations were done as follows. For space required, the four mandibular incisors were measured at their greatest mesiodistal crown diameter by means of a sliding Boley gauge with pointed beaks. All measurements were made with the gauge parallel to the incisal edges of the teeth, and all readings were to the nearest 0.1 mm (Figure 13-46). The values for unerupted canines and premolars were obtained by measuring their greatest mesiodistal crown diameter or their images on the periapical radiograph (Figure 13-47).

To reduce the radiographic enlargement, the formula recommended by Huckaba[41] was used in all radiographic measurements:

$$x = \frac{(y)(x^1)}{(y^1)}$$

where x is the estimated size of the permanent tooth; x^1, the radiographic size of the permanent teeth; y, the size of the primary mandibular second molar on the cast (Figure 13-48); and y^1, the radiographic size of the primary molar.

The values obtained for the mandibular incisors on the cast and those for the canines and premolars on the radiograph were added to provide the space required.

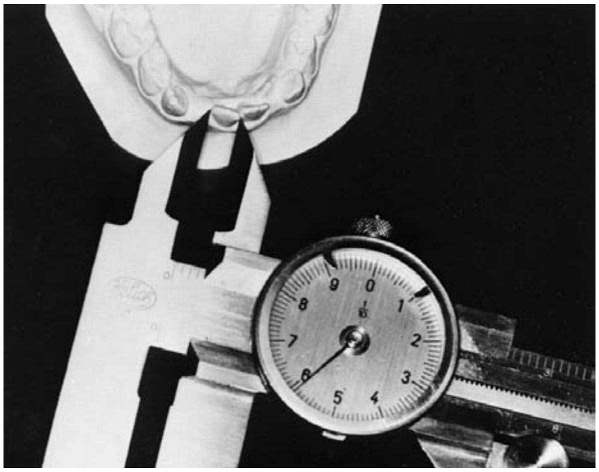


FIGURE 13-46 Measurement of space required on study models with a Boley gauge. Digital models allow this to be done efficiently with a variety of space analyses and size discrepancy evaluations.

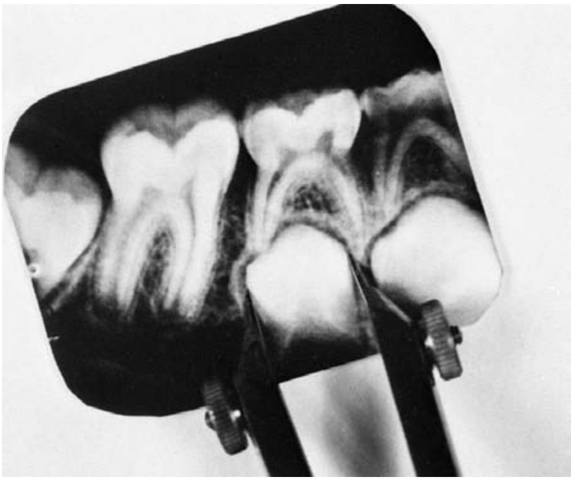


FIGURE 13-47 Measurement of space required on the periapical radiograph with a Boley gauge.

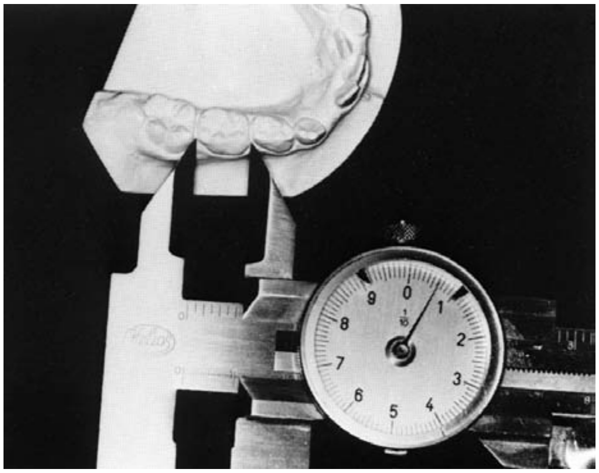


FIGURE 13-48 Measurement of the primary second molar on the study model with a Boley gauge to aid in assessing a radiographic enlargement.

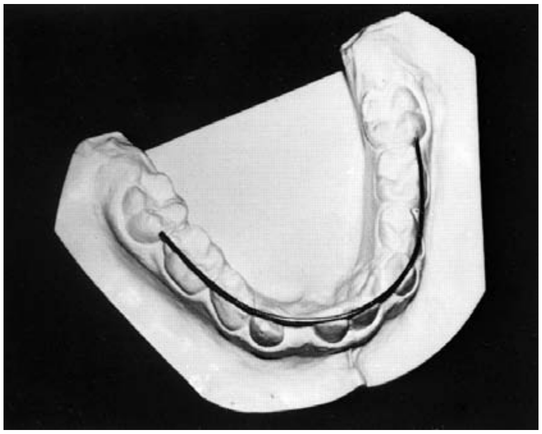


FIGURE 13-49 Measurement of space available on the study model with a brass ligature wire. Digital model analysis makes this manual measurement step unnecessary.

The space available was obtained by extending a brass wire from the mesiobuccal of the first permanent molar on one side to the mesiobuccal of the molar on the opposite side, passing through the buccal cusps and incisal edges of the remaining teeth (Figure 13-49). The wire was straightened carefully and measured with a pointed Boley gauge to the nearest 0.1 mm.

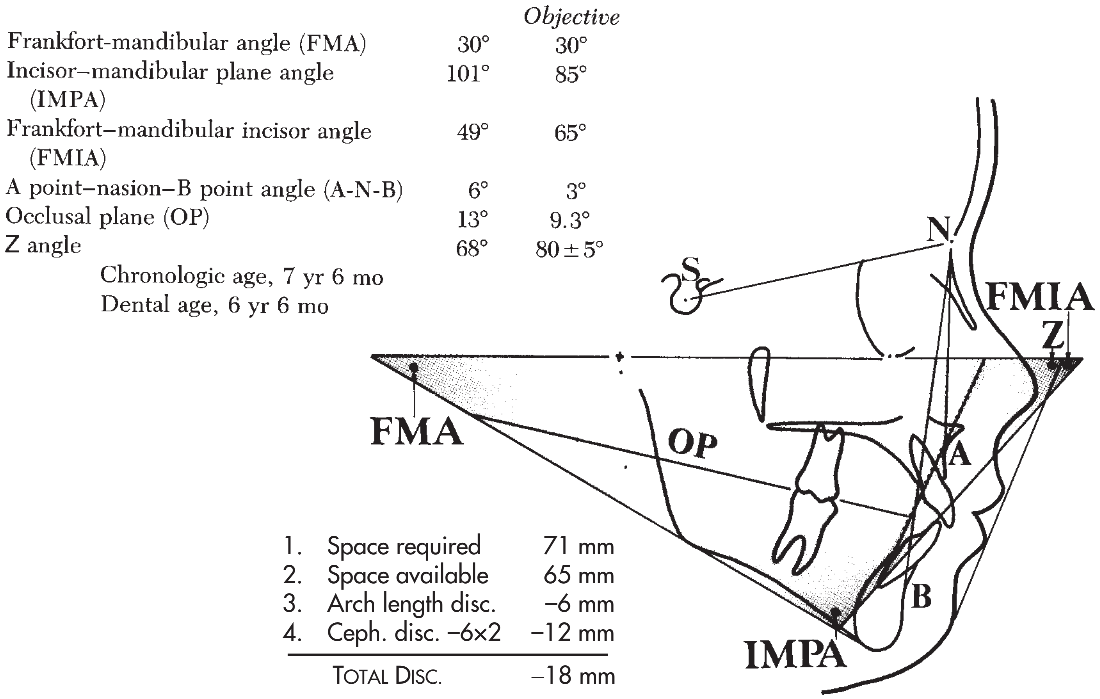
The difference in the values obtained for space required and space available was the amount of the discrepancy.

Tweed Method. The values for space required and space available were obtained as required for the conventional method (see Figures 13-46 to 13-49). An assessment of the relations between the axial inclination of the mandibular incisors and the basal bone was made on a tracing of the lateral cephalogram. The amount of alveolodental protrusion or retrusion was assessed and incorporated into the mixed-dentition analysis (Figure 13-50).

Tweed Foundation research has established the following relationships:

- When the FMA is between 21 and 29 degrees, the Frankfort mandibular incisor axis angle (FMIA) should be 68 degrees.
- When the FMA is 30 degrees or greater, the FMIA should be 65 degrees.
- When the FMA is 20 degrees or less, the incisor mandibular plane angle (IMPA) should not exceed 92 degrees.

If for a specific FMA (30 degrees) the FMIA (49 degrees) did not correspond, an objective line was traced to form the required FMIA (65 degrees). Then the distance between this objective line and the line that passed through the actual axial inclination of the mandibular incisors was measured on the occlusal plane with pointed calipers to the nearest 0.1 mm (6 mm). This figure was



		Objective
Frankfort-mandibular angle (FMA)	30°	30°
Incisor–mandibular plane angle (IMPA)	101°	85°
Frankfort–mandibular incisor angle (FMIA)	49°	65°
A point–nasion–B point angle (A-N-B)	6°	3°
Occlusal plane (OP)	13°	9.3°
Z angle	68°	80 ± 5°

Chronologic age, 7 yr 6 mo
Dental age, 6 yr 6 mo

1.	Space required	71 mm
2.	Space available	65 mm
3.	Arch length disc.	−6 mm
4.	Ceph. disc. −6×2	−12 mm
	TOTAL DISC.	−18 mm

FIGURE 13-50 Tweed method. Cephalometric correction to factor dental protrusion into space analysis.

multiplied by 2 to include right and left sides (12 mm). The total was the cephalometric correction, which then was added to the difference between space required in space available to yield the total discrepancy (see Figure 13-50).

Total Space Analysis. This method was divided into three areas—anterior, middle, and posterior—and the resulting values for each area were added together to yield the final deficit.

Anterior Area. For the anterior area the calculation of the difference between space required and space available was done as before. However, the space required included, in addition to tooth measurement and cephalometric correction, soft tissue modification.

Tooth Measurement. Measurements of mandibular incisor widths on the cast were added to the values obtained from the radiographic measurements of the canines. Both measurements were made according to a previously described technique (see Figures 13-46 to 13-48).

Cephalometric Correction. The cephalometric correction was calculated as for the Tweed method. However, instead of measurements being made of the distance (in millimeters) on the occlusal plane between the objective line and the line indicating the true axial inclination of the mandibular incisors, the actual FMIA (in degrees) was subtracted from the proposed angle, and the difference (in degrees) was multiplied by a constant (0.8) to give the difference in millimeters (Figure 13-51).

Soft Tissue Modification. Whereas the Tweed method added the anterior skeletal dental (hard tissue cephalometrics) relationships to the dental-oriented mixed-dentition analysis, this method also adds a consideration of the soft tissue profile. Thus, the teeth, jaws, and soft tissue are involved in the assessment.

The soft tissue modification was derived by measuring the Z angle of Merrifield[10,39] and adding the cephalometric correction (in degrees) to it. If the corrected Z angle was greater than 80 degrees, the mandibular incisor inclination was modified as necessary (up to an IMPA of about 92 degrees). If the corrected angle was less than 75 degrees, additional upright positioning of the mandibular incisors was necessary. Upper lip thickness was measured from the vermilion border of the lip to the greatest curvature of the labial surface of the central incisor. Total chin thickness was measured from the soft tissue chin to the N-B line.

If lip thickness was greater than chin thickness, the difference (in millimeters) was determined, multiplied by 2, and added to the space required. If it was less than or equal to chin thickness, no soft tissue modification was necessary.

Figure 13-52 portrays patient M.L., described in Figure 13-51, who had a typical Class I malocclusion with an alveolodental protrusion and an incompetent lip relationship (Figure 13-52, *A*). Note the improvement in muscle balance and facial harmony after serial extraction and active treatment (Figure 13-52, *B*).

The space available was obtained by placing a brass wire from the mesiobuccal of the primary first mandibular molar to the mesiobuccal of the opposite molar (Figure 13-53). The wire then was straightened and

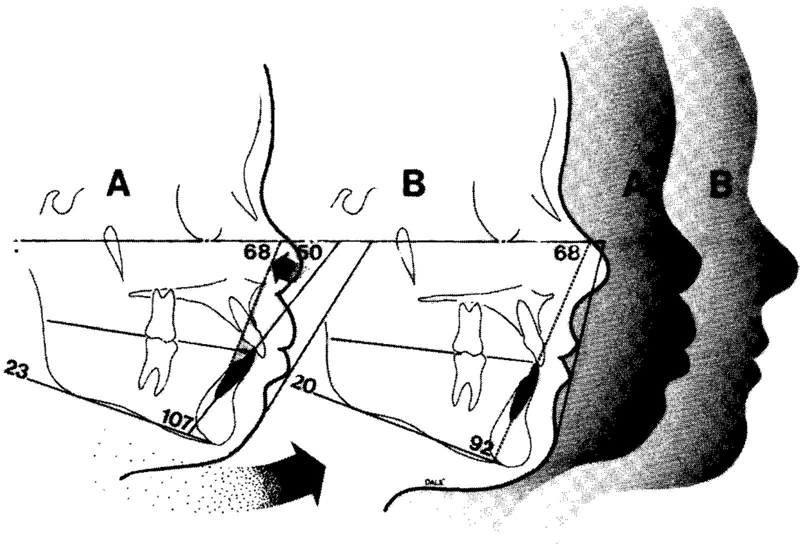


FIGURE 13-51 Total space analysis. Anterior arch cephalometric correction.

measured with a pointed caliper to the nearest 0.1 mm. This value was subtracted from the total space required to yield the deficit.

Middle Area. For the middle area calculations were made of the difference between space required and space available. In this instance, however, the mandibular curve of occlusion was considered.

Tooth Measurement. The crown widths of the permanent mandibular first molars were measured at their greatest mesiodistal diameter on the cast. These values were added to the measurements of the premolars obtained from the radiographs (see Figures 13-46 to 13-48).

Curve of Occlusion. The following describes the procedures for the calculations for the curve of occlusion.

The space required to level the mandibular curve of occlusion was determined (Figure 13-54). A flat object was placed on the occlusal surfaces of the mandibular teeth, contacting the permanent first molars and the incisors. The deepest point between this flat surface and the occlusal surfaces of the primary molars was measured on both sides. The curve of occlusion formula was applied, and the space required for leveling was determined. This was added to the tooth measurements to complete the space required. The curve of occlusion formula used the greatest depth of each side:

$$\frac{\text{Right side depth} + \text{Left side depth}}{2} + 0.5\,\text{mm}$$

The space available was determined by placing two brass wires (0.033 inch) from the mesiobuccal of the primary first molars to the distobuccal of the permanent first molars (Figure 13-55). These were measured as before, added together, and subtracted from the space required.

Posterior Area. For the posterior area, the space required and space available were determined (including that presently available and that predicted). The space required consisted of the sum of the mesiodistal widths of the two second and third molars, which were unerupted in these patients (Figure 13-56). Because they were unerupted, radiographic enlargements had to be calculated. However, the formula used for the conventional method was modified. In this instance the permanent mandibular first molars were substituted for the primary second molars. A second complication was that often the third molars were not visible on the radiographs. In this case, Wheeler's measurements were used, and the calculation was as follows:

$$x = \frac{y - x^1}{y^1}$$

where x is the estimated value of the permanent mandibular third molar in the individual patient; x^1 is Wheeler's values for third molars; y is the actual size of permanent mandibular first molar on the cast; and y^1 is Wheeler's value for first molars.

The space available consisted of the space presently available plus the estimated increase or prediction. The estimated increase was 3 mm per year (1.5 mm for each side) until 14 years in girls and 16 years in boys. Therefore the age of the patient was subtracted by 14 or 16. The result was multiplied by 3 to obtain the estimated increase for the individual patient. The space presently available was obtained by measuring the distance on the occlusal plane between a perpendicular line drawn from the occlusal plane tangent to the distal surface of the permanent first molar to the anterior border of the ramus on the lateral cephalometric tracing (see Figure 13-56). After the presently available space and the predicted

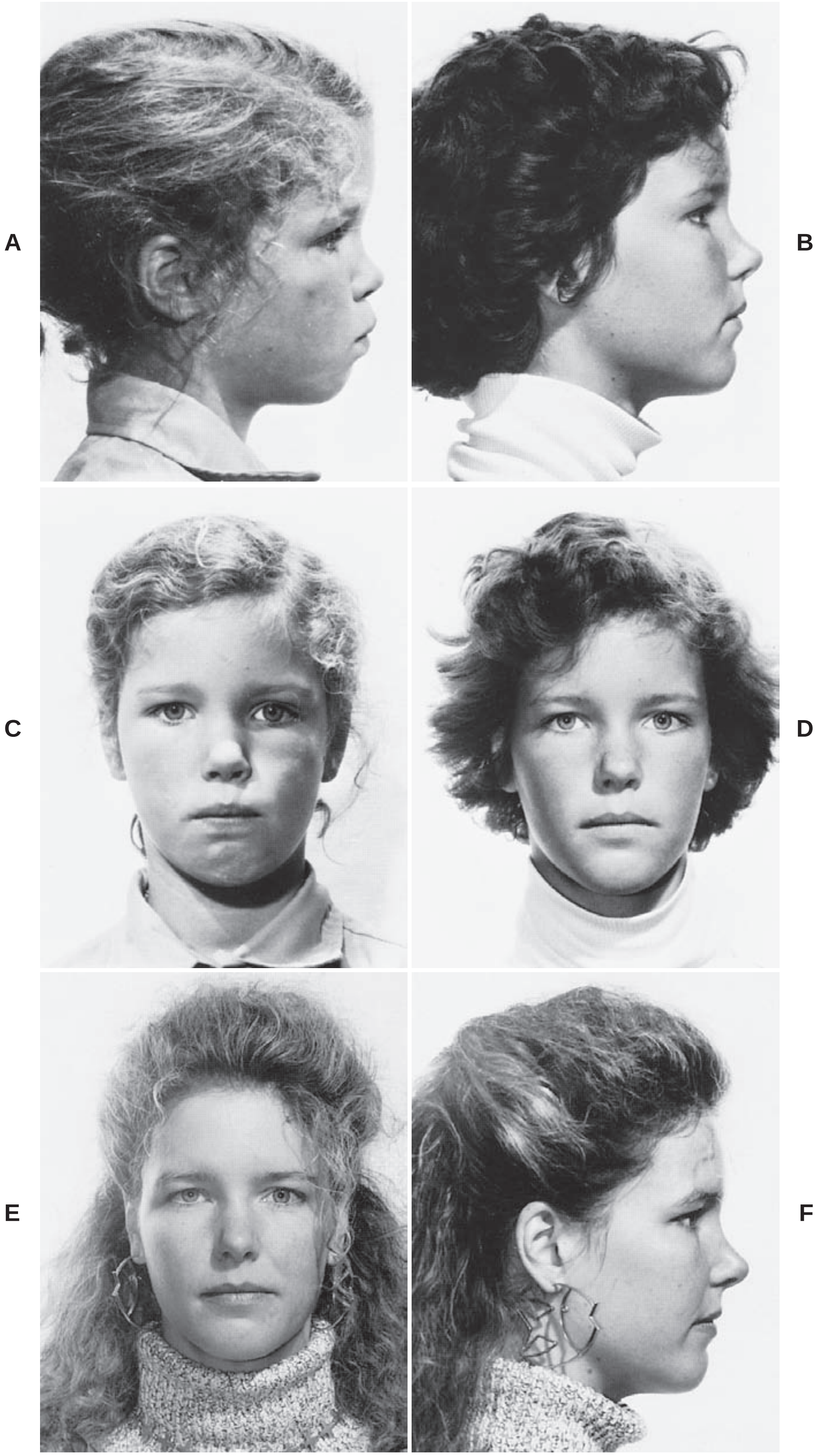


FIGURE 13-52 Patient M.L. **A, C,** Before treatment. **B, D,** After treatment. **E, F,** Balance and harmony persist as an adult, 15 years after orthodontic treatment.

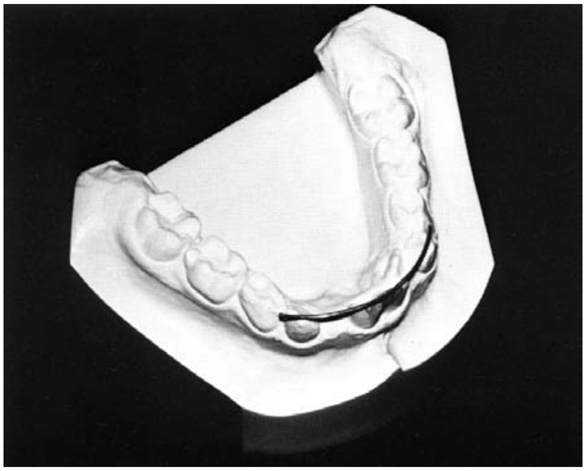


FIGURE 13-53 Total space analysis. Measurement of space available in the anterior area.

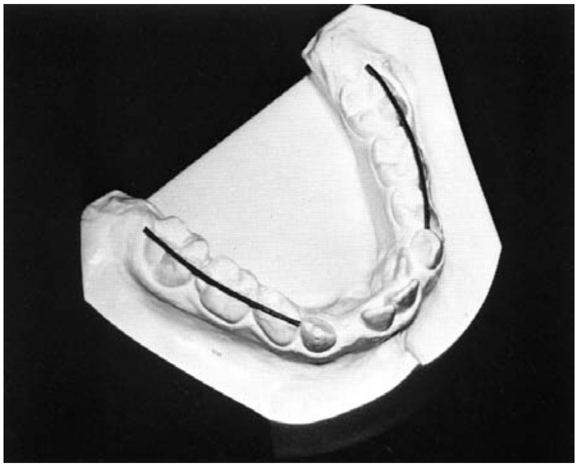


FIGURE 13-55 Total space analysis. Measurement of space available in the middle area.

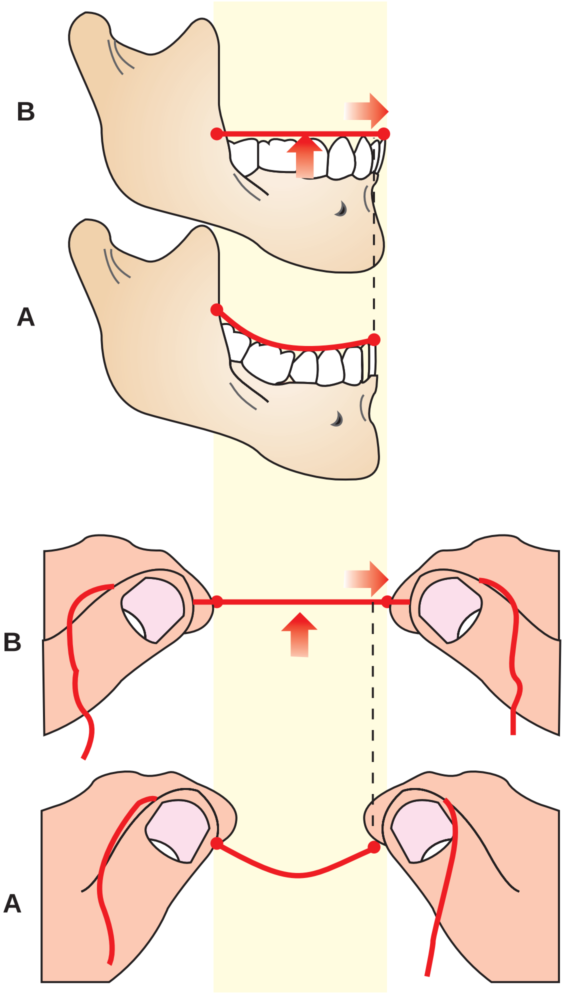


FIGURE 13-54 Total space analysis. Curve of occlusion. Leveling of the curve of Spee requires space.

space were totaled to give the space available, the space required was subtracted.

Discussion. Because the total space analysis involves the permanent molars, it was not possible to compare its results with those of the other two procedures. However, when the results of the conventional method are compared with those of the Tweed method, the differences become highly significant.

The assessment of axial inclination of the mandibular anterior teeth with respect to the basal bone must be included in the analysis of mixed-dentition malocclusion so that there will be harmony in the facial profile and stability in the dentition. The cephalometric correction in the Tweed method accounts for 9.8% of the space required, a considerable amount.

Table 13-2 illustrates the differences between the conventional method and the Tweed method in one of the subjects of the investigation. Comparison of the techniques makes it evident that completely different treatment plans will result.

Patient M.L. (see Figures 13-51 and 13-52) exemplifies an ideal serial extraction situation: a Class I mixed-dentition malocclusion with an anterior discrepancy in the form of an alveolodental protrusion and a posterior discrepancy with a medium angle facial pattern. The first premolars were extracted to correct the anterior discrepancy, and the third molars were extracted to correct the posterior discrepancy.

Patient M.R. (see Figures 13-85 and 13-87) also is a good example of a favorable serial extraction situation: a Class I mixed-dentition malocclusion with an anterior discrepancy in the form of a moderate alveolodental protrusion and a posterior discrepancy with a high-angle facial pattern. The same teeth were extracted as in patient M.L. for different reasons. The anterior discrepancy is

FIGURE 13-56 Total space analysis. Measurement of the available and predicted space in the posterior area.

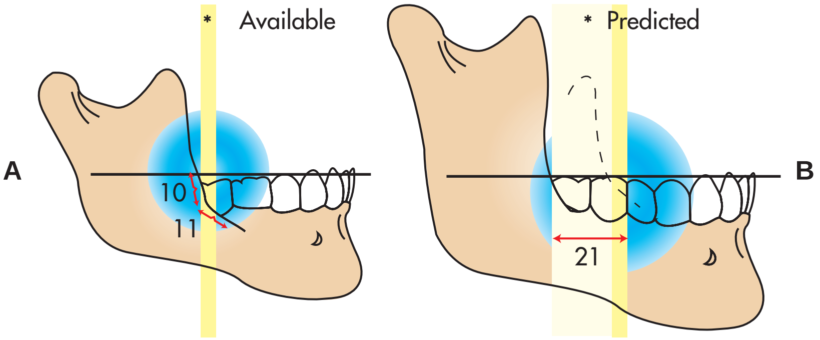


TABLE 13-2	Mixed-Dentition Analysis: Comparison of the Conventional and Tweed Methods	
LS	**Conventional Method (mm)**	**Tweed Method (mm)**
Space required	−69.3	−69.3
Space available	+69.1	+69.1
Discrepancy	−0.2	−0.2
Cephalometric Correction	—	−8.0
Total discrepancy	−0.2	−8.2
Difference between two methods	—	−8.0

more related to the alveolodental protrusion in patient M.L. than in patient M.R. The posterior discrepancy is more related to the high-angle facial pattern in patient M.R. than in patient M.L. Thus each individual is treated differently depending on the results of the various diagnostic procedures, including total space analysis. Total analysis may thus result in extraction of varied teeth or non-extraction, with mechanotherapy varying to match the correction of individual discrepancies from a balanced dentofacial form.

Timing of Guided Primary Tooth Removal

Three factors may be applied by the clinician in deciding the optimal time for the removal of teeth in the guidance of occlusion:

1. The effect of extraction of the primary tooth on the eruption of its permanent successor
2. The amount of root formation at the time of emergence
3. The length of time for the attainment of various stages of root development

Serial extraction, if carried out too early in the primary dentition, can delay the eruption of permanent successors. In the case of early extraction of the primary molar, Fanning[42] reported an initial spurt in eruption of the premolar. This leveled off and the tooth then remained stationary, erupting later than its antimere with a normally shedding primary precursor. If serial extraction is initiated with the extraction of the primary canines, the length of the roots of the premolars is not an important consideration. If, however, the orthodontist is contemplating initiating serial extraction by removing the primary first molars, the length of the root of the premolar is an important consideration and guide for the commencement of the procedure.[43]

The relative eruptive rates of the permanent canines and first premolars influence the decision about which primary teeth should be extracted. If, for example, during an examination of the radiographs, the orthodontist observes the permanent mandibular first premolar crown ahead of the permanent canine crown, the premolar with less than one-half its root formed, and the mandibular incisors crowded, the primary canine should be extracted to relieve the crowding. The primary first molar should be left until the first premolar has attained one-half its root length. If, on examining the radiographs, the orthodontist observes the premolar crown even with the canine crown, the premolar with one-half its root formed, and an alveolodental protrusion, the primary first molar should be extracted to encourage the emergence of its successor.

Dental age, assessed particularly by root length, is an essential requirement in the decision of a serial extraction program and in the initiation of interceptive and definitive fixed appliance treatment. A knowledge of root development, relative eruptive rates, and the emergence of permanent teeth (Figure 13-57), together with root resorption of the primary teeth and the factors that influence these processes, is mandatory in the timing of serial extraction.

TREATMENT

The authors adhere to the principles and objectives of the Tweed philosophy. Clinically, Tweed advocated maximal facial harmony and balance. To achieve this goal, he recognized that mandibular incisor teeth must be placed upright over basal bone. The primary objective

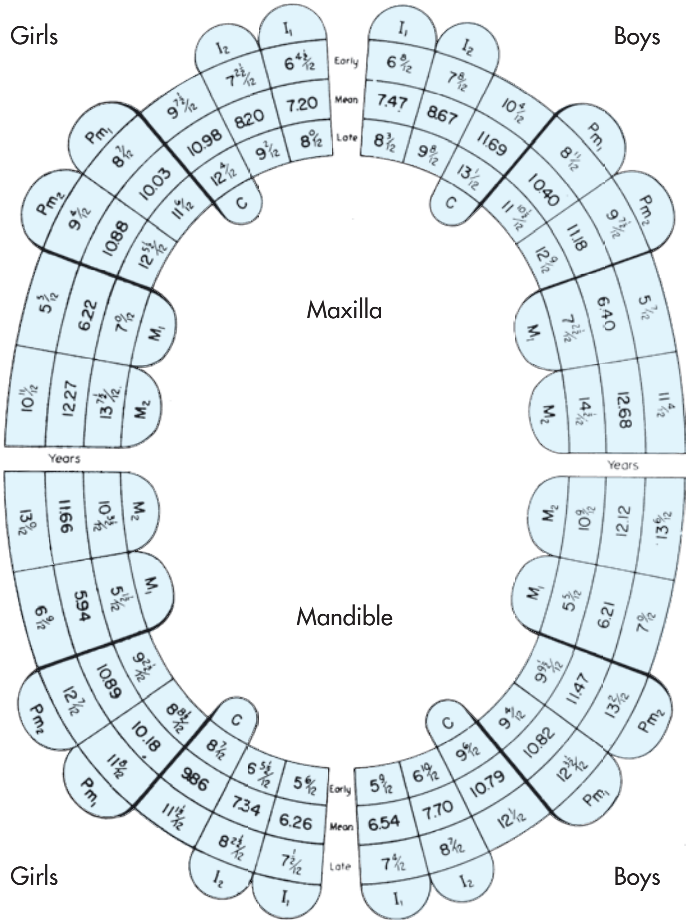


FIGURE 13-57 Assessment of dental age by means of tooth emergence (±1 SD). This is a classic study taken from records of 93,000 children and demonstrates individual tooth variability and sex-linked timing of eruption. *(From Hurme VO: Ranges in normalcy in eruption of permanent teeth,* J Dent Child *16:11, 1949.)*

in treatment is to obtain maximal health, aesthetics, function, and stability. Specifically it is excellence in tooth alignment, arch form, and axial inclination of the teeth, with optimal occlusal intercuspation of the maxillary and mandibular dentitions.

Objectives of treatment include the following:

1. Decrease in the FMA, indicating a favorable rotation of the mandible
2. Decrease in the IMPA, indicating the reduction of the alveolodental protrusion
3. Increase in the FMIA, also indicating an upright positioning of the mandibular incisor teeth
4. Decrease in the occlusal plane angle throughout treatment, indicating that one is not extruding the posterior teeth or dumping the anterior teeth forward
5. Decrease in the ANB (A point–nasion–B point) angle, indicating a correction of the skeletal discrepancy
6. Increase in Merrifield's Z angle, indicating improvement in facial harmony and balance
7. No lateral, anterior, or posterior expansion of the dentition. This is substantiated by the scientific investigations of Enlow,[23] who describes specifically the boundaries of the nasomaxillary complex (Figure 13-58).

Many orthodontists have found from bitter experience that they cannot extend arch length posteriorly, anteriorly, or laterally unless the position of the teeth results from environmental factors such as premature loss of the primary teeth. Most of the problems during treatment and retention have been associated with creating space and maintaining alignment where teeth have not been extracted.[44] Teeth that have not been placed in the correct position relative to the skeletal pattern and soft tissue matrix are more likely to change after fixed appliances have been removed. The ideal conditions for stability are achieved when teeth are placed in a harmonious relationship early. Long-term use of mandibular fixed retainers may be needed to reduce age-related maturational changes in the lower anterior segment. These should be maintained in patients for a prolonged time to preserve the incisor alignment when the mandible grows horizontally (see Chapters 8 and 27).

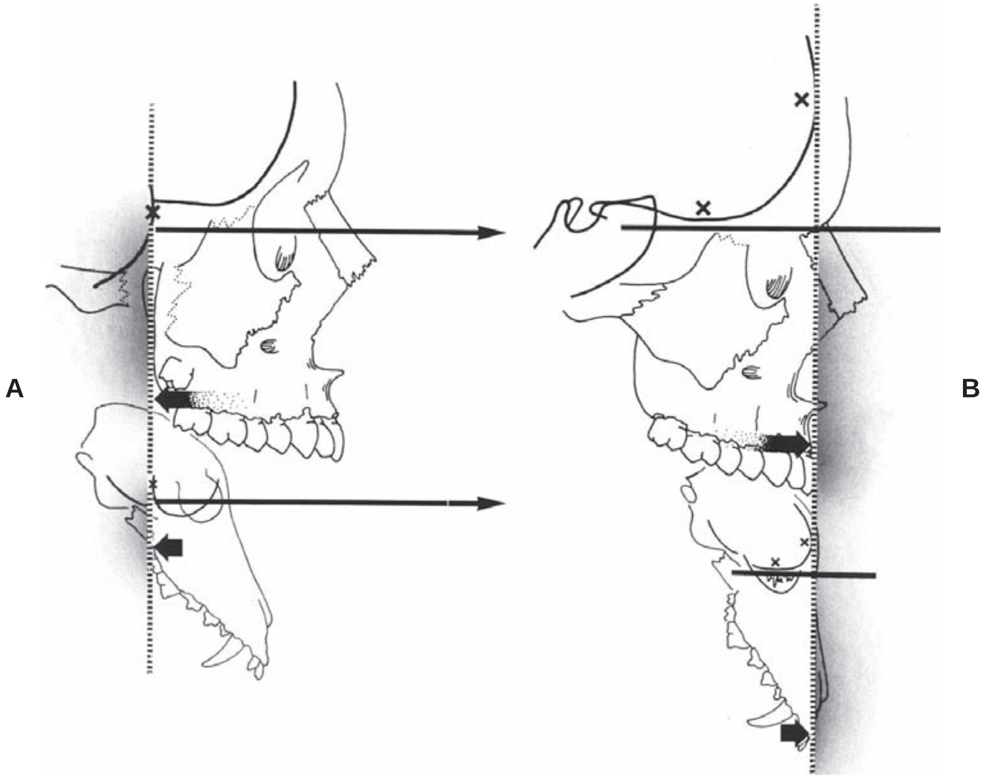


FIGURE 13-58 **A,** Posterior limits of the nasomaxillary area: a line perpendicular to the line of sight passing through the junction of the anterior and middle cranial fossae. **B,** Anterior limit of the nasomaxillary complex: a line extending from the internal surface of the frontal bone and running perpendicular to the ethmoid. *(Adapted from Enlow DH, Hans MG:* Essentials of facial growth*, 2nd ed, Ann Arbor, MI, 2008, Needham Press.)*

Serial extraction allows teeth to become aligned when they emerge into the oral cavity, rather than to remain in a crowded unfavorable condition for several years. In the case of alveolodental protrusion, the procedure allows the mandibular incisors to be positioned upright lingually into a position of balance. This alone will reduce mechanotherapy by 6 months and contribute to the stability of the treatment result. In many of these patients, the need for retention is minimal. However, the orthodontist must remember that under ideal serial extraction conditions, the orthodontist is not dealing with severe skeletal discrepancies or severe overjet and overbite problems. The need for long-term retention is greater when skeletal discrepancies have complicated the orthodontic treatment.

One may ask, "If the roots of the permanent incisor teeth complete their formation in a more favorable position, is their stability enhanced?" It seems logical that if a tooth completes its formation in a site where it will remain when treatment is completed, it will be more stable. Conversely, if a tooth is left in a crowded, tipped, and rotated position for several years and then moved to a new position relatively rapidly, it will be less stable for a time and will require a longer retention period.

One also may ask, "Does the initiation of serial extraction with the removal of primary teeth always mean that the permanent teeth will be removed?" Once initiated, serial extraction more often than not will culminate in the extraction of four premolar teeth because arch length, which is deficient to begin with, is reduced even more. Despite a thorough diagnosis, the treatment plan occasionally needs to be changed to nonextraction treatment. *The practitioner should always be prepared to treat without extraction if it appears that this can be done successfully with stability.* At the beginning of treatment the parents should be informed that extractions may be necessary to produce a successful and stable treatment result. Later, they will be relieved and happy if extractions are not necessary.

An important objective in using the serial extraction technique is to make treatment easier and mechanotherapy less complicated, less expensive, and shorter (especially during the teenage years). Treatment can be divided into four categories:

1. A period of interceptive guidance, extending about 5 years from age 7.5 to 12.5 years. This consists entirely of the guidance of occlusion, including serial extraction and/or space maintenance, and is the most ideal service that can be provided. Unfortunately, production of excellent occlusion with serial extraction and/or space maintenance alone is possible in only a few patients. When guidance without further appliances is accomplished, it is most rewarding and

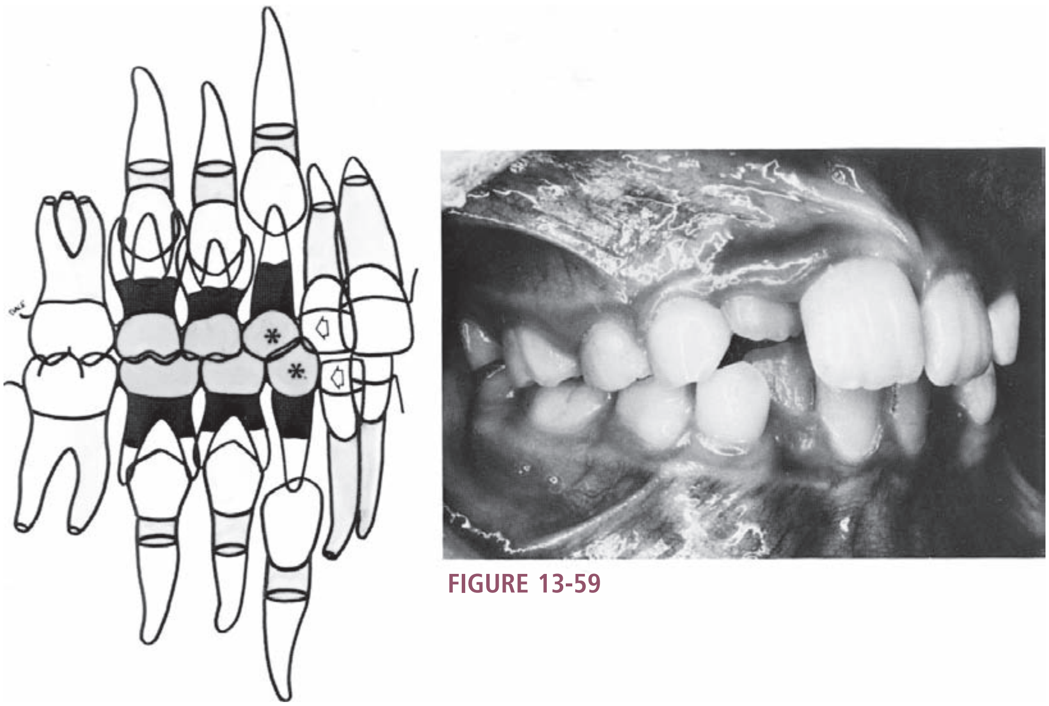


FIGURE 13-59

satisfying because the results are achieved without mechanotherapy.

2. An initial period of interceptive guidance, extending about 4 years from age 7.5 to 11.5 years, plus a second period of fixed appliance treatment extending about 1 year from 11.5 to 12.5 years). Class I and specific types of dental Class II malocclusions fall into this category.
3. An initial period of interceptive treatment, extending about 1 year from 8.5 to 9.5 years, plus a period of interceptive guidance extending about 2 years from 9.5 to 11.5 years, and a second period of mechanotherapy extending about 1.5 years from 11.5 to 13 years. Class II malocclusions fall primarily into this category.
4. A period of fixed appliance treatment, extending for 1.5 to 3 years from age 11.5 to 14.5 years. Serial extraction is not involved in this treatment. Wherever possible, the orthodontist should try to avoid extensive treatment in the teenage period due to potential adverse sociopsychological concerns that influence patient cooperation.

Of course, these are general classifications. They may vary considerably depending on the individual patient, the malocclusion, and the dental age.

CLASS I TREATMENT

Serial extraction has been classically characterized by the removal of the primary canines, primary first molars, and permanent first premolars. With scientific investigation and clinical experience, serial extraction has become increasingly sophisticated and precise. Results will be more rewarding if the orthodontist does not cling to a particular sequence but varies it according to the diagnosis and therapeutic goals. The sequence that the orthodontist believes is indicated for each patient should be selected.[45]

Treatment Procedures: Interceptive Guidance, Active Treatment

Serial Extraction in Class I Treatment.

Group A: Anterior Discrepancy—Crowding. This is a typical serial extraction problem: severe crowding, a developing Class I malocclusion, a favorable overjet-overbite relation of the incisor teeth, and an ideal orthognathic facial pattern (Figure 13-59). Examination of the radiographs often will reveal a crescent pattern of resorption on the mesial of the primary canine roots (see Figure 13-6). This is an indication of a true hereditary tooth-size/jaw-size discrepancy. Radiographic evaluation indicates that the first premolars are emerging favorably, ahead of the permanent canines. None of the unerupted permanent teeth have reached one-half root length. Because of this the primary first molars would not be extracted. The primary canines should be extracted to relieve the incisor crowding.

Step 1: Extraction of the primary canines.

Step 2: Extraction of the primary first molars. The incisor crowding has improved, the overbite has

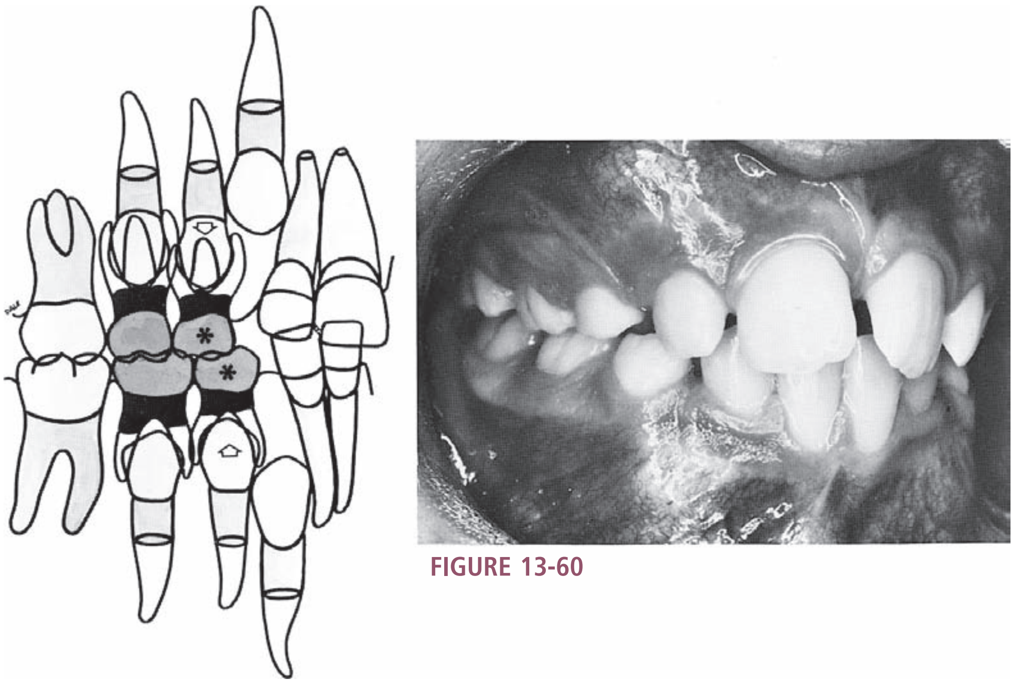


FIGURE 13-60

increased, and the extraction site is reduced in size (Figure 13-60). The radiographs reveal that the first premolars have reached one-half root length. Now is the time to extract the primary first molars to encourage the eruption of the first premolar teeth.

Step 3: Extraction of the first premolars. These teeth are emerging into the oral cavity (Figure 13-61). Because the permanent canines have developed beyond one-half root length, indicating that they are prepared to accelerate their eruption, the orthodontist extracts the premolars.

Step 4: Fixed appliance treatment. This is the typical result of serial extraction, a relatively deep overbite with a disto-axial inclination of the canines, a mesio-axial inclination of the second premolars, a Class I molar relationship, an improved alignment of the incisors, and residual spaces at the extraction sites (Figure 13-62).

Step 5: Retention. When mechanotherapy is completed, an ideal occlusion should be observed, with minimal overjet-overbite relationship of the anterior teeth, parallel canine and premolar roots, ideal arch form, and no spaces (Figure 13-63). In addition, the dentition should be aligned in harmony with the craniofacial skeleton and soft tissue matrix.

Step 6: Postretention. Again, an ideal occlusion with stability should be evident (Figure 13-64). Initiating the serial extraction procedure with elimination of the primary mandibular canines tends to deepen the overbite. The primary first molars should be extracted when the underlying first premolars have reached one-half their root length. If this is done, risk of collapse will be minimal. If the mandibular incisors are crowded, the primary canines should be extracted first, in preference to the primary first molars. The orthodontist rarely will be satisfied with the improved alignment of the incisors when the primary molars are extracted first. Again, the decision is based on the relative position and length of the roots of the first premolars and canines. Figure 13-64 illustrates the occlusion 18 years after treatment.

Group B: Anterior Discrepancy—Alveolodental Protrusion. A minor irregularity of the incisor teeth exists. Instead of crowding, the patient has an alveolodental protrusion (Figure 13-65). The crowns of the first premolars and canines are at the same level. However, the canines are beyond one-half root length and are erupting faster than the premolars. Because the first premolars have one-half their root length developed, the primary first molars should be extracted to accelerate eruption of the first premolars. This will ensure that the premolars emerge into the oral cavity ahead of the canines. Timing is most important to prevent the formation of a knife-edge ridge.

Step 1: Extraction of the primary first molars.

Step 2: Extraction of the primary canines and first premolars. When the first premolars have emerged sufficiently, they are extracted along with whatever primary canines remain (Figure 13-66). No effort is made to prevent lingual tipping of the incisor teeth because the objective is to reduce the alveolodental protrusion.

Step 3: Fixed appliance treatment. Note how beautifully the dentition is aligning itself (Figure 13-67). Little mechanical treatment will be required.

Step 4: Retention. Retention in the mandible is less crucial because minimal irregularity was present before treatment (Figure 13-68).

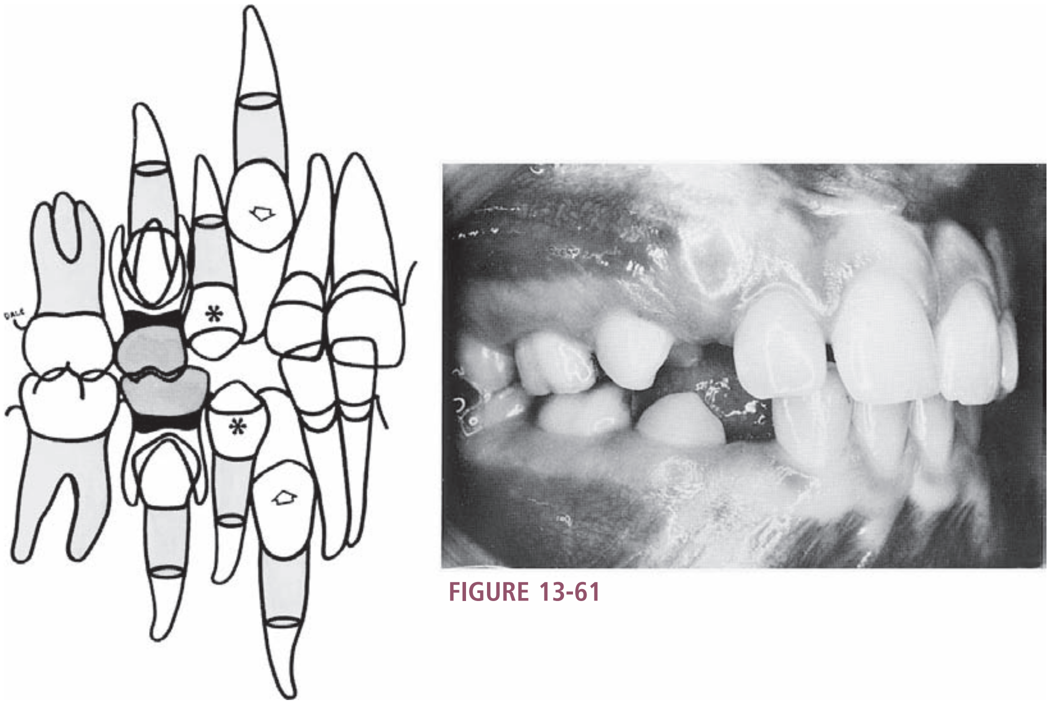


FIGURE 13-61

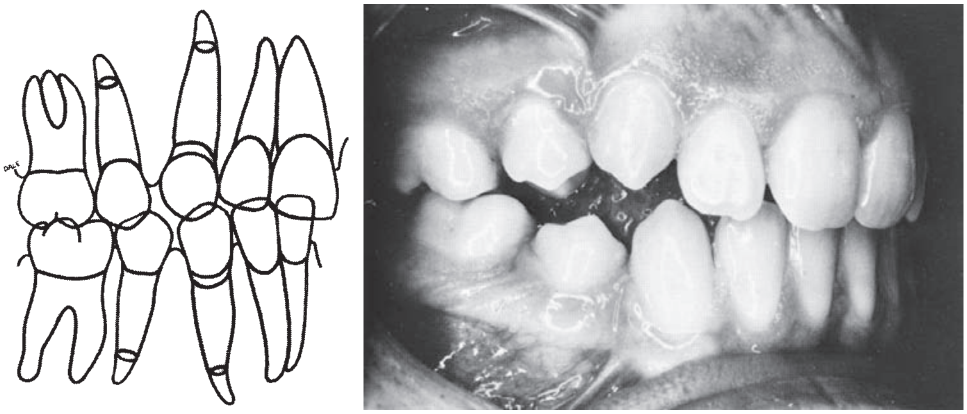


FIGURE 13-62

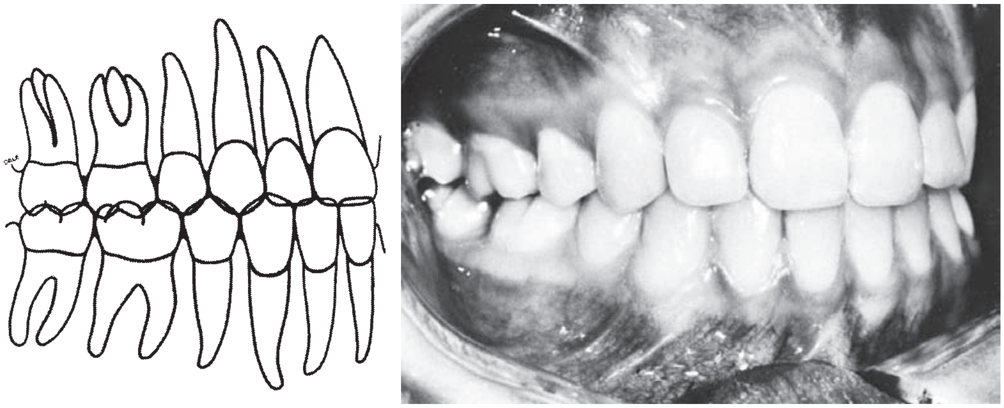


FIGURE 13-63

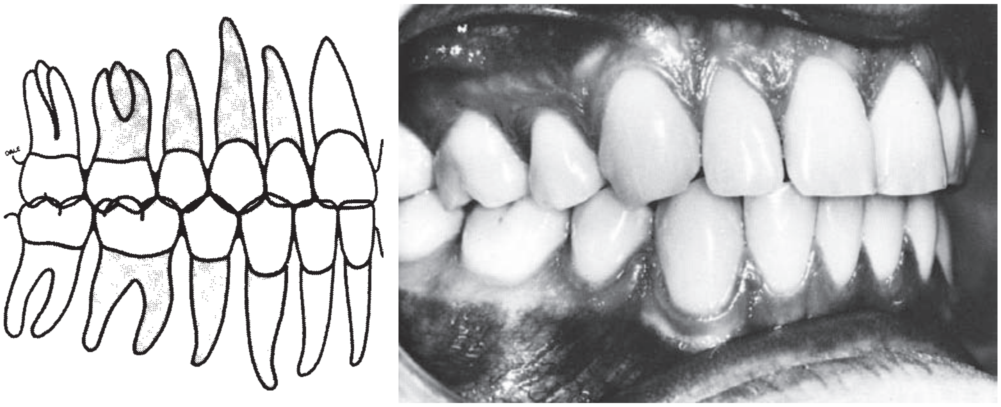


FIGURE 13-64

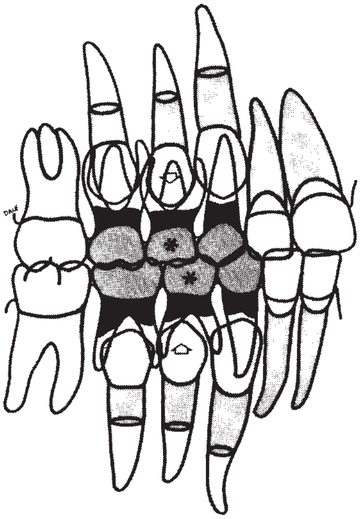


FIGURE 13-65

Group C: Middle Discrepancy—Impacted Canines. The tooth-size/jaw-size discrepancy is severe, causing premature exfoliation of the primary canines (Figure 13-69). Note the splaying of the incisors because of crowding in the apical area. Often parents interpret this spacing as evidence for nonextraction treatment. The orthodontist must explain that this is a sign of severe crowding. The radiograph will reveal that the first premolars are ahead of the canines in eruption and have attained one-half their root length. Treatment begins with the extraction of the primary first molars (remember, here primary canines have been lost).

The impacted permanent maxillary canines may cause severe splaying of the maxillary incisors to such an extent that the lateral incisors do not contact the primary canines (see Figure 13-69, *bottom right*). In this situation, extracting the primary canines first does little good. Better advice is to extract the primary first molars to encourage the first premolars to emerge as early as possible. The canines then will have space to migrate away from the apices of the incisors and begin their eruption into the oral cavity. In this instance the practitioner should be concerned more with correcting canine crowding than with incisor irregularity. Every effort should be made to avoid correcting the incisors with fixed appliances for fear of causing the incisor roots to resorb.

Step 1: Extraction of the primary first molars.

Step 2: Extraction of the first premolars. For reasons explained in Group A, step 3, the first premolars are now due for extraction (Figure 13-70).

Step 3: Fixed appliance treatment. Note the typical result of serial extraction (Figure 13-71).

Step 4: Retention. Again, note the desired result of mechanotherapy (Figure 13-72).

Group D: Enucleation in the Mandible. If it is evident that the canines will emerge into the oral cavity ahead of the first premolars, the primary first molars can be extracted and the first premolars may be enucleated (Figure 13-73). This will encourage distal migration of the canines as they erupt.

*Step 1: E*xtraction of the primary first molars and enucleation of the mandibular first premolars.

Step 2: Extraction of the primary maxillary canines and maxillary first premolars. In the maxilla the first premolars usually emerge before the canines (Figure 13-74). Therefore enucleation is less likely to be indicated. At this point the mandibular canines can be observed emerging favorably into the oral cavity.

Step 3: Mechanotherapy. (Figure 13-75). The patient is now ready for the fixed appliance multibracket appliance treatment.

Step 4: Retention.

Group E: Enucleation in the Maxilla and Mandible. On occasion the canines in the maxilla and mandible erupt before the first premolars (Figure 13-76). If this is the case, the orthodontist might elect to extract the primary canines and first molars and enucleate the first premolars. This is acceptable if absolutely no opportunity exists to place fixed appliances at the completion of serial extraction. Otherwise, an alternative to enucleation is almost always preferable (see Group F).

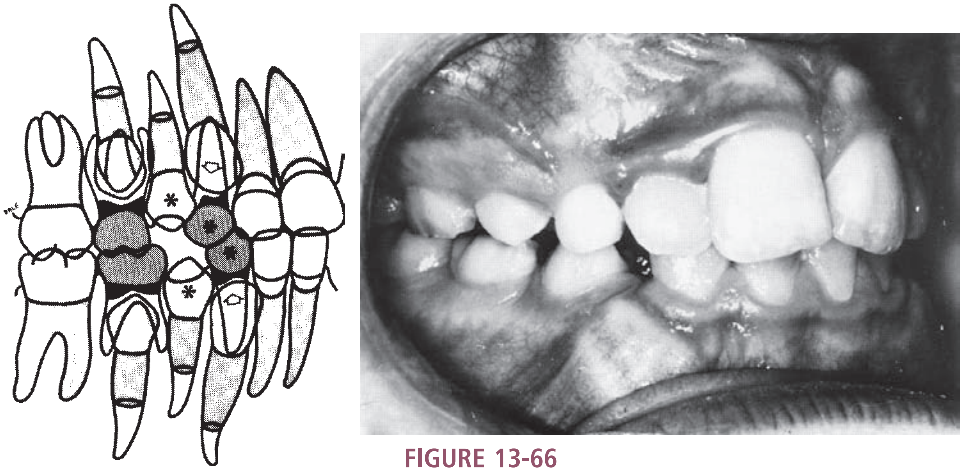


FIGURE 13-66

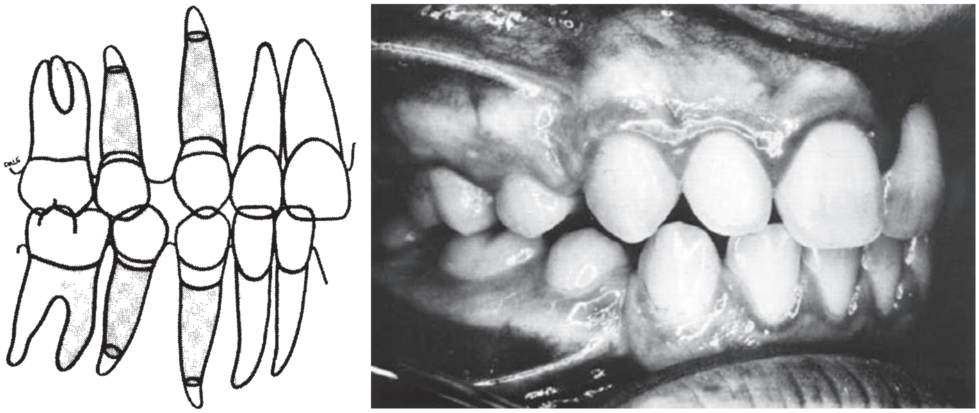


FIGURE 13-67

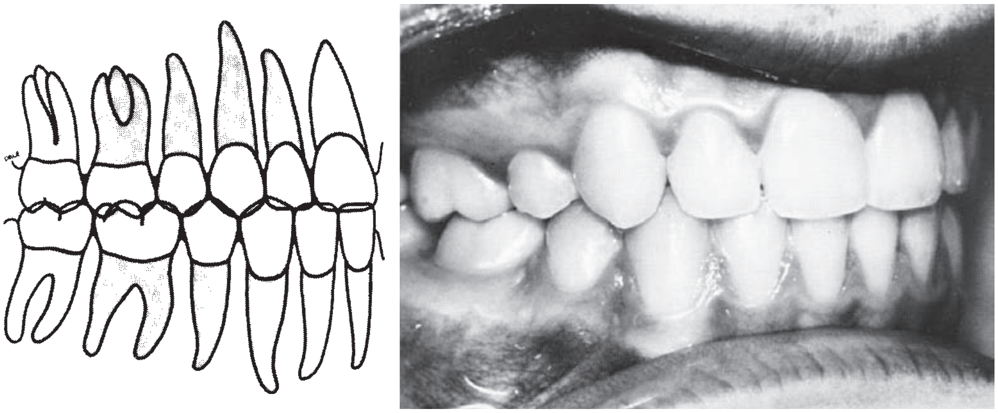


FIGURE 13-68

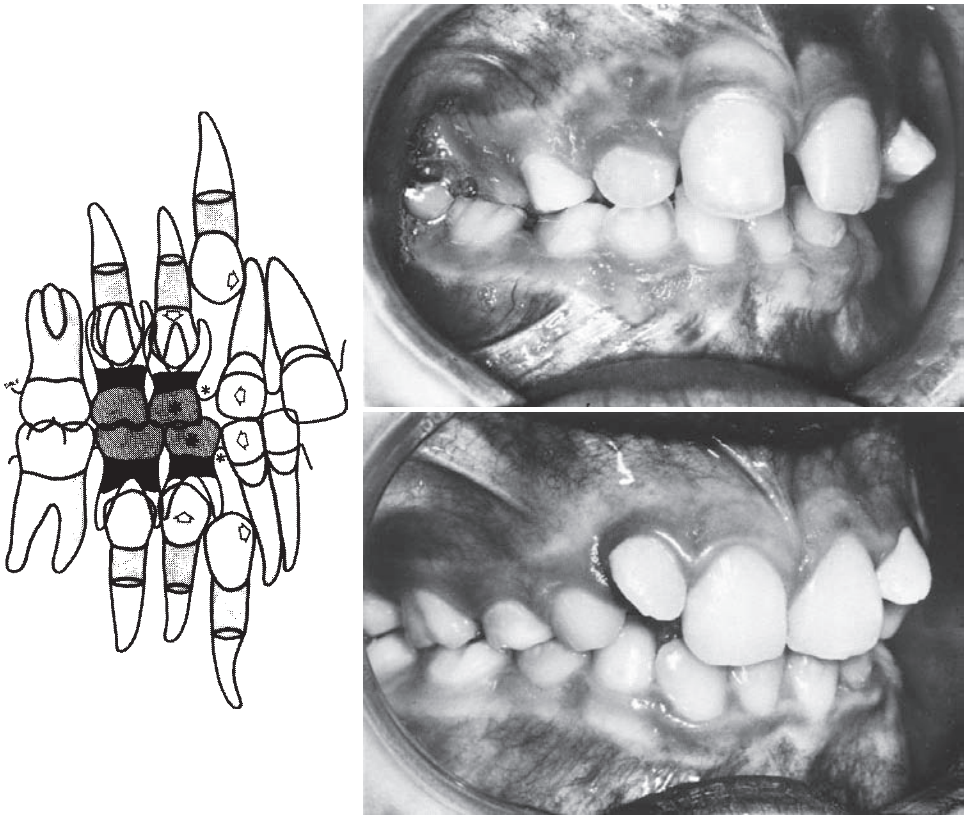


FIGURE 13-69

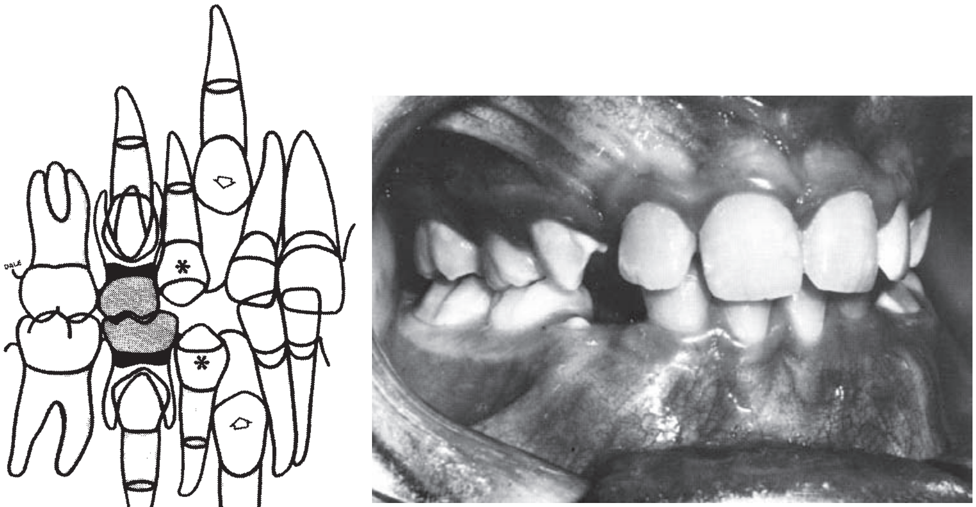


FIGURE 13-70

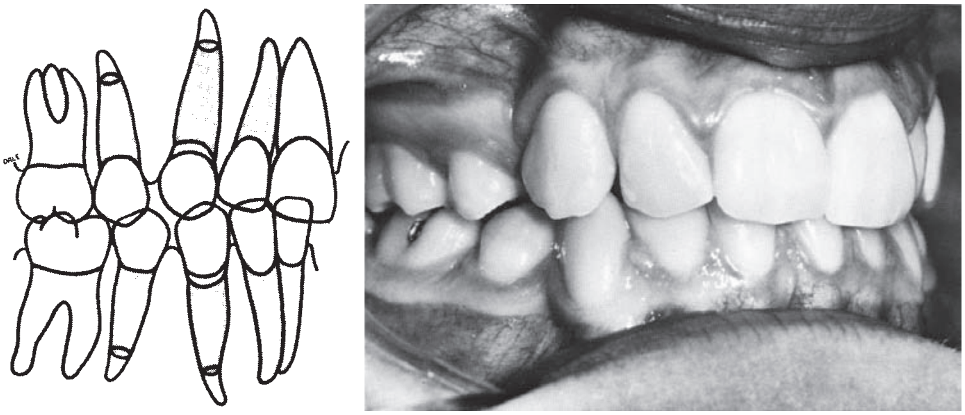


FIGURE 13-71

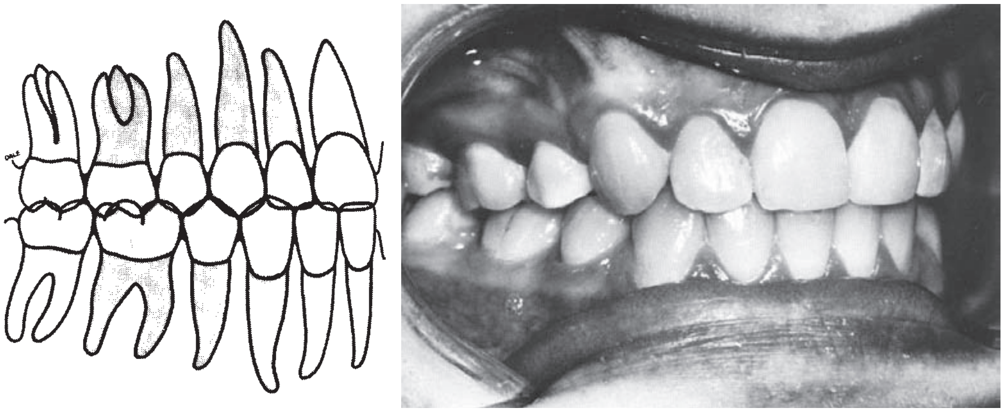


FIGURE 13-72

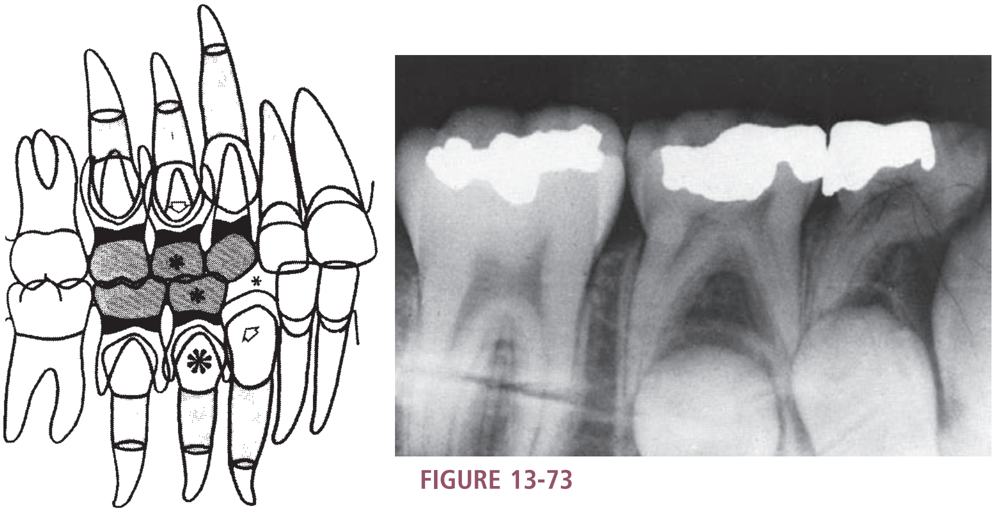


FIGURE 13-73

Step 1: Extraction of primary canines and primary first molars and enucleation of the first premolars.

Step 2: Mechanotherapy. (Figure 13-77). The patient is now ready for the appliance treatment.

Step 3: Retention.

Group F: Alternative to Enucleation. When the permanent canines are erupting ahead of the first premolars, enucleation of the premolars should be avoided if an opportunity exists to place fixed appliances at the completion of serial extraction (Figure 13-78). When the first premolars have attained one-half their root length, the primary first molars should be extracted.

Step 1:

Step 1: Extraction of the primary first molars.

Step 2: Extraction of the primary maxillary canines, maxillary first premolars, and primary mandibular second molars. Some 6 to 9 months later, when the emerging mandibular first premolar appears to be obstructed by the mesial contour of the primary second molar, the orthodontist should extract the offending tooth (Figure 13-79). However, this sequence is usually not necessary in the maxillary dentition.

Step 3: Extraction of the mandibular first premolars. When these teeth emerge sufficiently, they are extracted (Figure 13-80).

Step 4: Mechanotherapy. With this particular sequence the least desirable extraction result is achieved (Figure 13-81). However, extraction does not prolong the fixed appliance treatment significantly.

Step 5: Retention.

Group G: Interproximal Reduction. Rarely should the mesial surfaces of the primary canines be reduced. These rare occurrences include when the practitioner does not intend to extract the permanent teeth and where a localized interference results in rotation of the lateral incisor.

Occasionally in nonextraction malocclusions the primary second molars will be retained for an unusually long time. Because these teeth are wider mesiodistally than the underlying second premolars, they force the first premolars into a forward position in the dental arch and

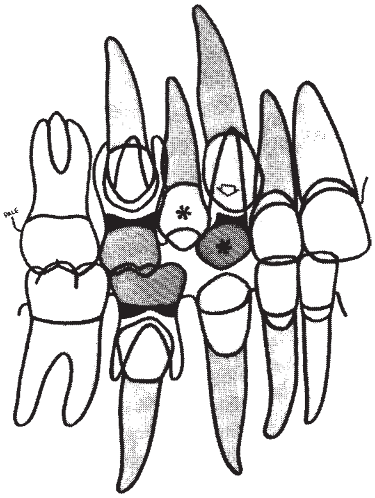


FIGURE 13-74

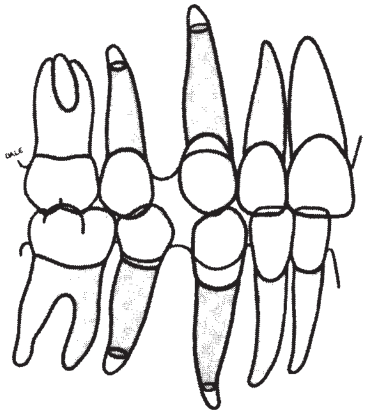


FIGURE 13-75

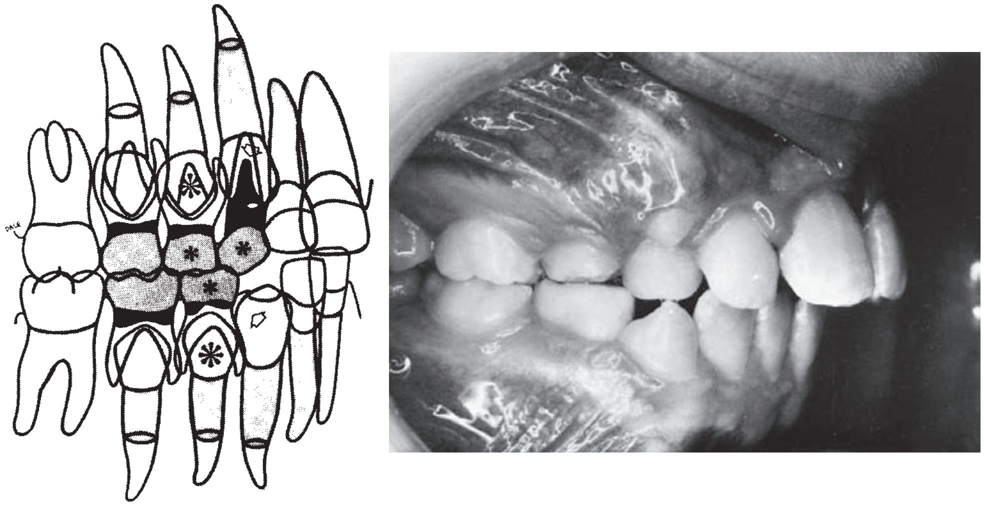


FIGURE 13-76

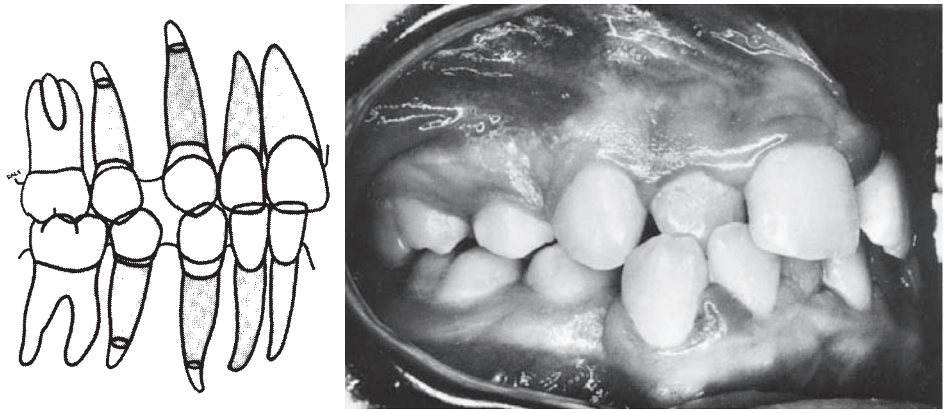


FIGURE 13-77

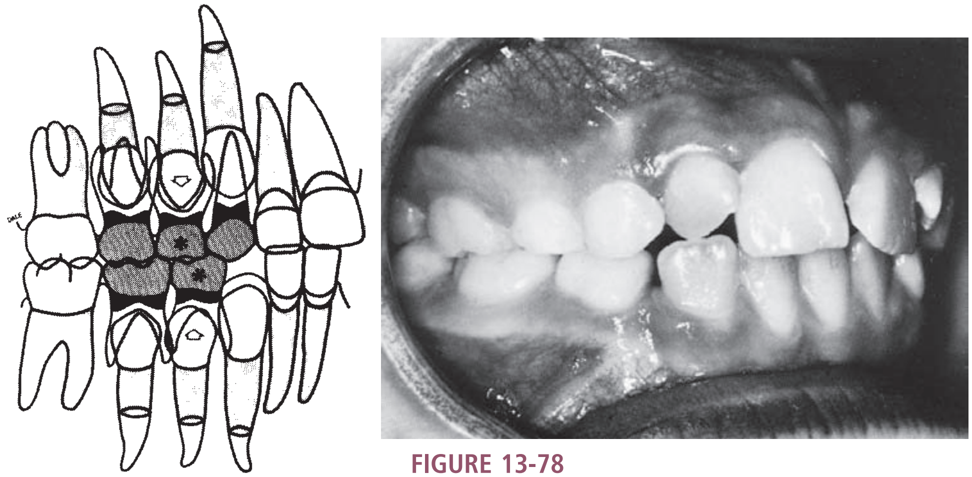


FIGURE 13-78

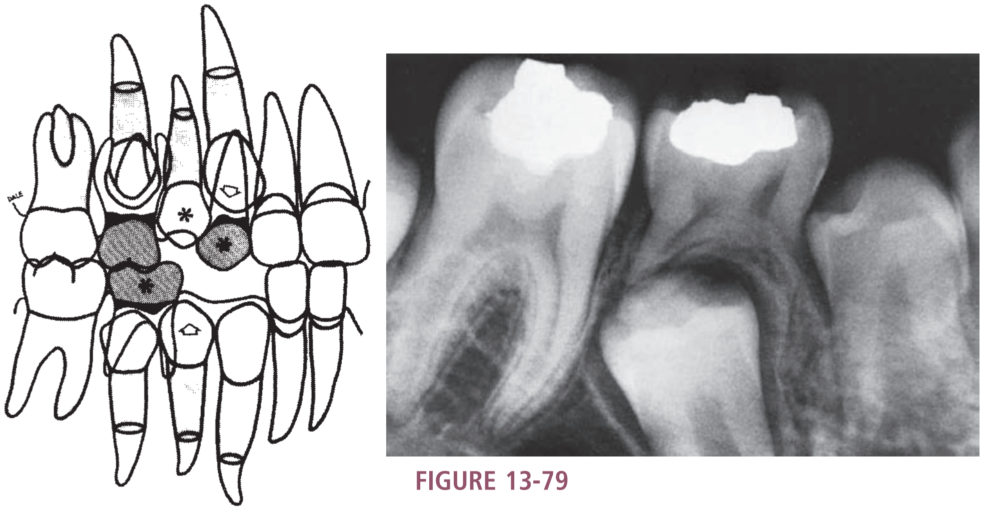


FIGURE 13-79

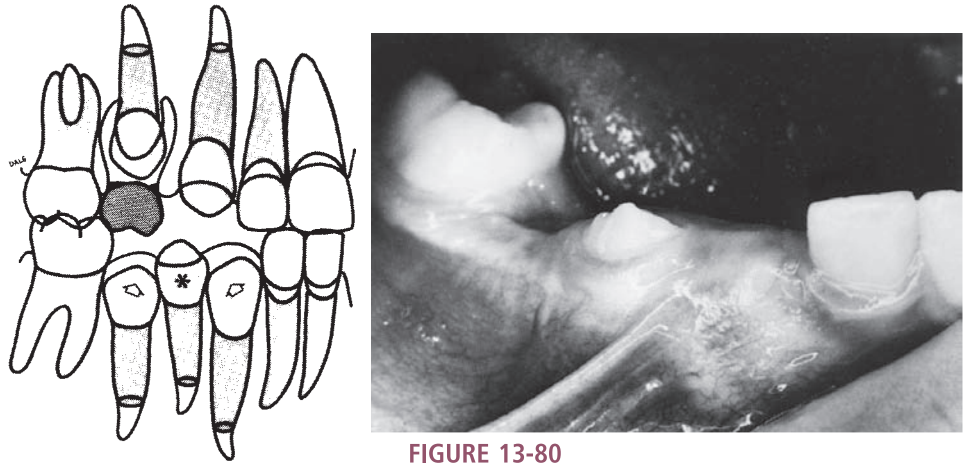


FIGURE 13-80

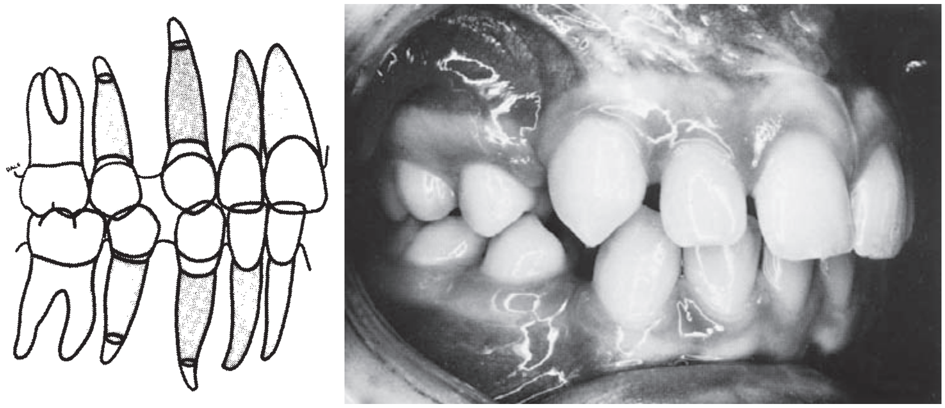


FIGURE 13-81

thus influence the permanent canines (Figure 13-82, *A*). The long retention of these primary second molars also may interfere with the eruption of the first premolars after the permanent canines have emerged (Figure 13-82, *B*). In each instance the mesial surface of the primary second molars should be reduced by the amount of the leeway space. This usually results in a favorable alignment of the permanent teeth (Figure 13-83).

The orthodontist may find it necessary at times to reduce the distal surfaces of the primary second molars (Figure 13-84) to ensure conversion of a straight terminal plane into a mesial step in preparation for a Class I relationship of the permanent first molars. This is accomplished when the primary maxillary second molars are exfoliated before those in the mandible and when space is present to allow the molars to move mesially. Ideally the mandibular molars should be lost first. (For more detailed discussion of interproximal reduction of primary teeth, read the articles by Hotz,[3] Northway,[46,47] and Valencia[48]).

Group H: Congenital Absence. Of utmost importance in patients with congenital absence of some teeth is to proceed with the conventional orthodontic diagnosis and treatment planning as if the teeth were present. Then treatment may proceed to cope with the missing tooth or teeth. Whether the teeth are missing as a result of injury, disease, or developmental aberration matters little. Which teeth are missing and what is left to work with are the important factors in total correction of the malocclusion.

Maxillary Incisors: The maxillary lateral incisors are frequently missing or malformed. The percentage varies depending on the study consulted but in most practices is about 5% of the patients treated.

If a maxillary lateral incisor is congenitally absent, the dentition should be allowed to emerge completely before fixed appliance treatment begins. The orthodontist and primary care dentist should examine the crown of the canine carefully after emergence before deciding to place it in the lateral incisor position or its usual position.[49] The orthodontist should not rely on radiographs to evaluate the shape of unerupted teeth. Placing implant or fixed bridge restorations rather than using canines as lateral incisors may be needed if the size discrepancy exceeds the ability to restore the cuspid to appear as a lateral incisor. When canines are used as laterals, the

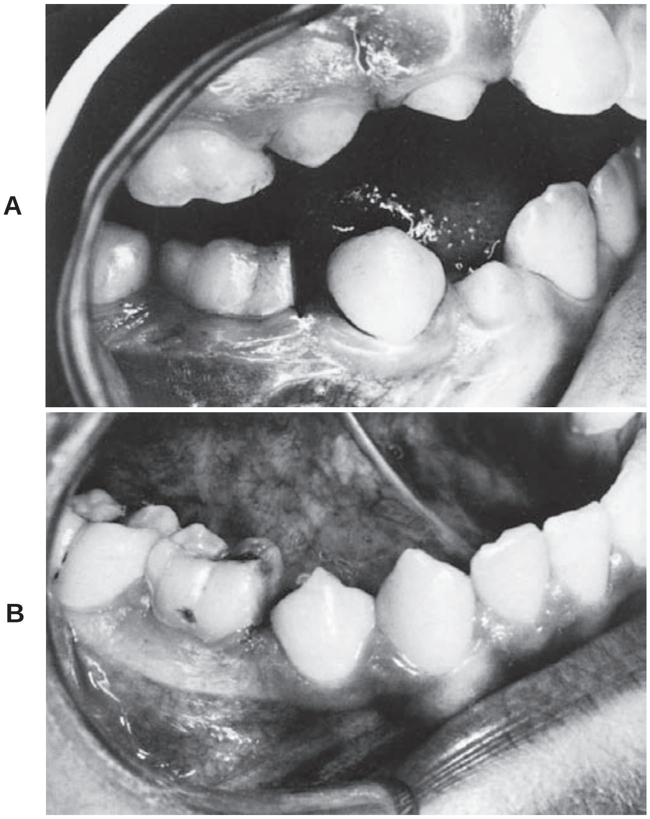


FIGURE 13-82 Interproximal reduction of the primary second molar to allow for emergence of **(A)** the permanent canine and **(B)** the first premolar.

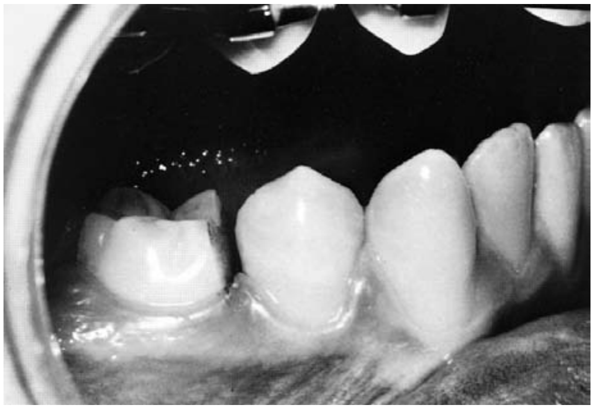


FIGURE 13-83 Favorable alignment after reduction of the primary second molar.

orthodontist needs to be aware of arch size discrepancies between the arches and the potential to develop interproximal spaces during the retention period; in many instances aesthetic considerations are the final deciding factor on whether or not to proceed with cuspid substitution.[50–52]

Mandibular Incisors: The patient in Figure 13-85 was treated by extraction of the mandibular central incisors. Such extraction disturbs arch length balance. Patients who have severe recession and malposition of the central incisors can be treated by routine serial extraction. The extraction of mandibular incisors, especially during development, definitely is not recommended; it complicates the total treatment plan and necessitates a compromise result. Every effort should be made to maintain the mandibular incisors, especially in unilateral situations.

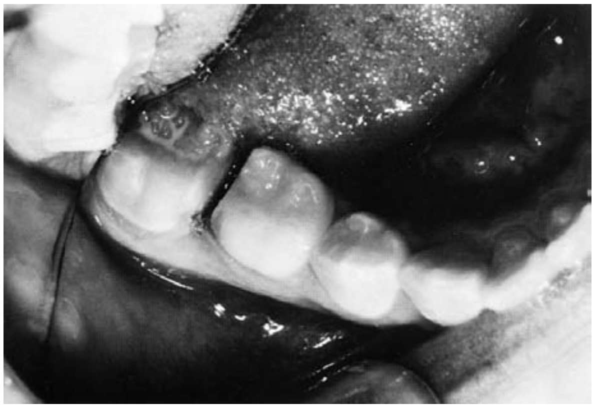


FIGURE 13-84 Reduction of the distal surface of the primary second molar to convert a straight terminal plane into a mesial step.

Sometimes the orthodontist is faced with a single missing lower incisor. To repeat, every effort should be made to maintain the mandibular incisors, especially in the unilateral situation and during development. If one of the mandibular incisors is missing, it may be advisable to avoid extracting a premolar in that quadrant and use the canine as an incisor. If it is an extraction case, the molars on the affected side will be in a Class I relationship; if it is not, they will be in a Class III relationship.

Premolars: Figure 13-26 illustrates a patient who had two maxillary first premolars missing. The clinical appearance that resulted was unusual. The canines erupted into the premolar locations, and the primary canines were retained. The treatment plan was altered to include extraction of the primary canines and movement of the permanent canines forward into their proper position with a resultant.

Class II Molar Relationship. Mandibular second premolars frequently are missing. Depending on the basic orthodontic diagnosis, treatment may involve moving the molars forward or replacing the missing teeth with bridges. Treatment for Class II malocclusions that involved extractions may include moving the maxillary protruding incisors into the space provided by the extraction of the maxillary first premolars. Correction for a Class II molar relationship may involve moving the mandibular molars forward into the second premolar area, where the teeth are congenitally absent.

Mandibular second premolars constantly are presenting difficulties in orthodontic treatment. They often are missing or erupting in the wrong direction and often are badly shaped with the potential for a size difference from the left to right side. The use of TADs to bring lower

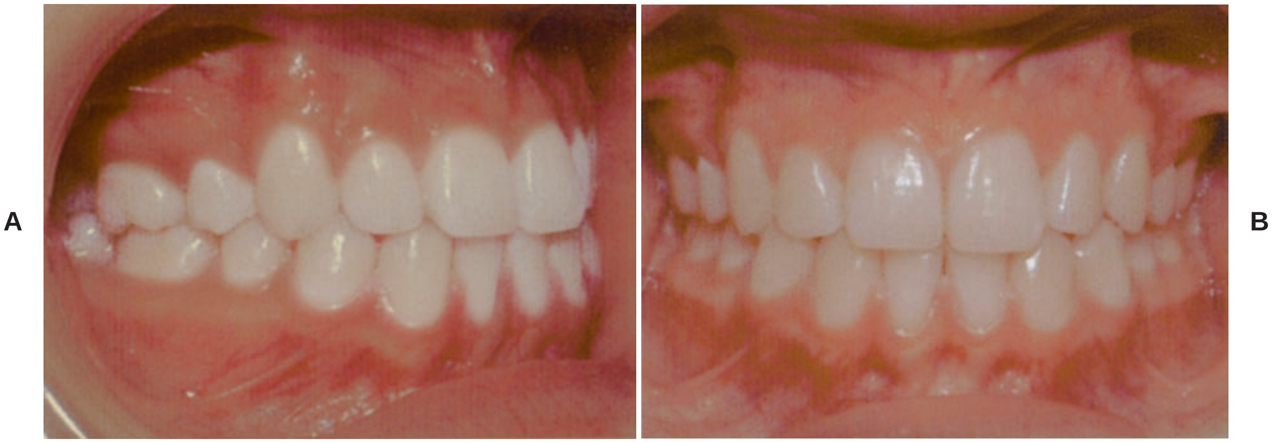


FIGURE 13-85 **A** and **B,** Alignment of the mandibular dentition after treatment in a patient with congenital absence of two incisors. The first premolars were extracted in the maxilla.

molars mesially without taxing anterior anchorage allows for space closure without adverse lingual tipping of the lower incisor teeth.

When one mandibular second premolar is congenitally missing, the clinician should proceed with serial extraction as normally done, extracting all four primary canines or primary first molars, depending on the development. When the four first premolars have emerged, three of them are extracted. In a quadrant where the second premolar is missing, the primary second molar is extracted. The first premolar then is moved into the second premolar site. This allows space for the canine to emerge. Occasionally the primary second molar must be extracted earlier to allow the first premolar to emerge into a more distal position.

Garn and Lewis[53] have shown that in a congenital absence, more often than not the treatment will not require extraction. In other words, congenital absence of teeth is related to small teeth; thus serial extraction is not indicated.

If the diagnosis indicates the extraction of four second premolars or if the four teeth are congenitally missing, serial extraction is not indicated. Second premolar extractions are prescribed for a borderline tooth-size/jaw-size discrepancy in which the incisors are upright over basal bone. With extraction of the second premolars the minimal crowding in the anterior area is corrected by using a fraction of the extraction space and without producing an alveolodental retrusion. To encourage the emergence of second premolars ahead of the first premolars by extraction of the primary second molars early is difficult. Second premolars are notoriously slow in their eruption. Furthermore, if the primary second molars are extracted early, the permanent first molars may move mesially too rapidly. Second premolars are extracted when they have emerged partially into the oral cavity.

Often the question is asked about creating a dished-in face as the ultimate result of serial extraction when the four first premolar teeth are extracted. All orthodontists should be concerned about creating dished-in faces. *That is why serial extraction should be done only on a specific group of patients and only after a comprehensive diagnosis.* Because of this concern the clinician should monitor the position of the mandibular incisors constantly. These should be allowed to tip lingually to the desired position and then held.

Some patients have a dished-in profile whether treated by extraction or nonextraction or left untreated. They exhibit a maxillary mandibular alveolodental retrusion, a low mandibular plane angle, a deep overbite of the incisor teeth, a short anterior facial height, a prominent chin, a prominent nose, and a tense perioral musculature. If a severe tooth-size/jaw-size discrepancy is superimposed, extraction may be called for to produce a stable result. To defer consideration of extraction until all the permanent teeth have emerged is usually advisable with this facial pattern rather than to perform serial extraction. If the orthodontist performs serial extraction, the orthodontist must use extreme caution and use holding appliances.[42,54,55]

A word of caution is necessary at this point regarding holding appliances, the labial upright positioning of permanent mandibular incisors, and the distal movement of permanent mandibular first molars by the use of fixed appliances including lip bumpers. Even the use of a lower fixed lingual arch can result in the impaction of the erupting mandibular second molars, another reason for continued monitoring during tooth eruption.

Typical Patient for Class I Serial Extraction

A typical Class I malocclusion with an anterior discrepancy manifested by an alveolodental protrusion and a posterior discrepancy manifested by a high-angle configuration is illustrated by patient M.R. (Figures 13-86 and 13-87). The dentition when the patient came for examination and consultation is presented in Figure 13-86, *A*. The primary canines already had been

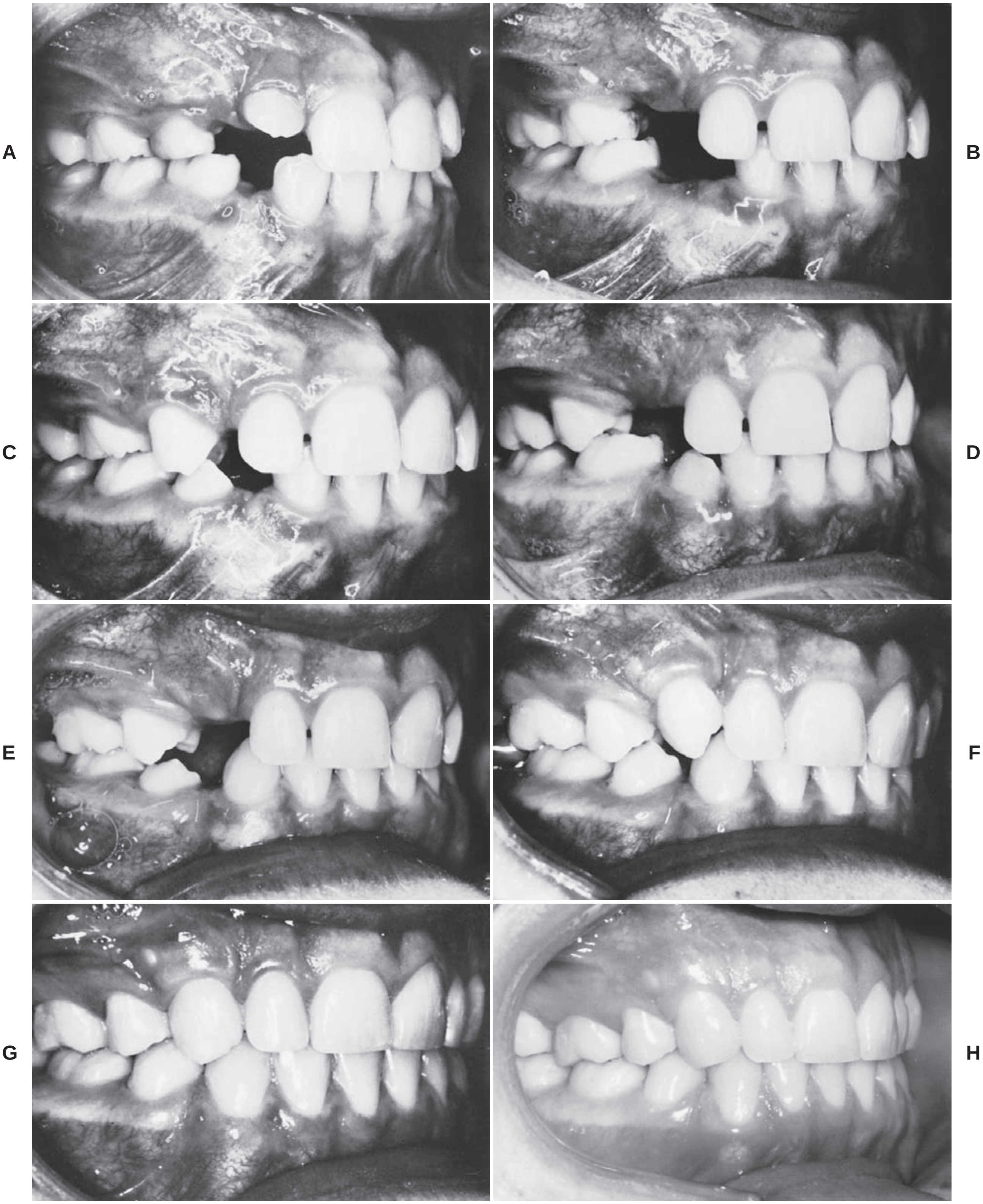


FIGURE 13-86 Patient M.R. **A,** At initial examination. The primary canines have been extracted. **B,** After extraction of primary first molars. **C,** Before extraction of the first premolars. **D,** Emergence of the permanent mandibular canines. **E,** Emergence of the second premolars. **F,** Before fixed appliance treatment. **G,** After fixed appliance treatment. **H,** Fifteen years after treatment.

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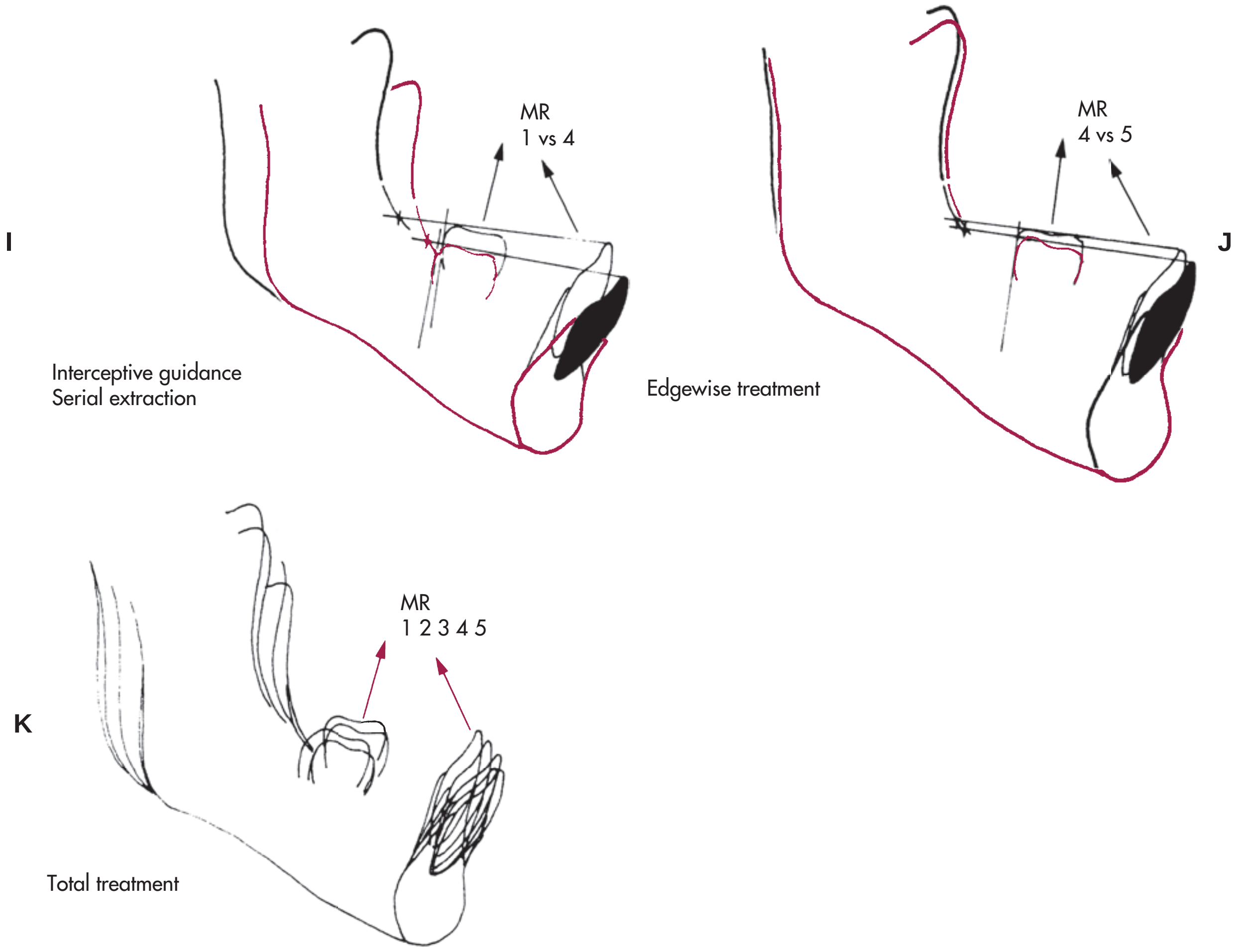

FIGURE 13-86, cont'd **I,** Response during interceptive guidance. **J,** Considerably less response during edgewise treatment. **K,** Response as indicated by the five cephalometric tracings (*1–5*) that were taken in each step in the treatment: (*1*) before treatment; (*2*) after extraction of the primary canines; (*3*) after extraction of the primary first molar; (*4*) after extraction of the first premolar; and (*5*) after fixed appliance treatment.

extracted. In such patients, the clinician extracts the primary first molars to encourage the emergence of the first premolars so that they can be extracted as early as possible. This corrects the alveolodental protrusion by upright positioning of the incisor teeth.

With a relatively straight alignment of the incisor teeth, one does not need to extract the primary canines early. In Figure 13-86, *B*, the primary first molars have been extracted. Note the early eruption of the maxillary first premolar. A large restoration and a periapical infection of the primary molars possibly were factors in this situation. The orthodontist should wait until the other premolars have emerged into the oral cavity before advising extraction of these teeth (see Figure 13-86, *B*). Note that in Figure 13-86, *C*, the four premolars have been extracted and the incisor teeth are beginning to become upright over basal bone. In Figure 13-86, *D*, the permanent mandibular canines are beginning to emerge into the oral cavity. Note that the maxillary right primary second molar has been lost early. The premolar has emerged and the first molar has drifted somewhat mesially. In Figure 13-86, *E*, all the primary second molars have now been lost and the second premolars are emerging. Note the further upright positioning of the incisor teeth. With the emergence of the permanent maxillary canines and second molars, this patient is now ready for fixed appliance treatment (Figure 13-86, *F*). Figure 13-86, *G*, illustrates the end result, and *H*, the occlusion 15 years after retention. Cephalometric radiographs were taken of patient M.R. at the following times:

1. Before treatment
2. After extraction of the primary canines
3. After extraction of the primary first molars
4. After extraction of the permanent first premolars
5. After edgewise treatment

The response to serial extraction during interceptive guidance—superimpositions of cephalometric tracings numbers 1 and 4 (Figure 13-86, *I*)—is significantly greater than the response during the edgewise

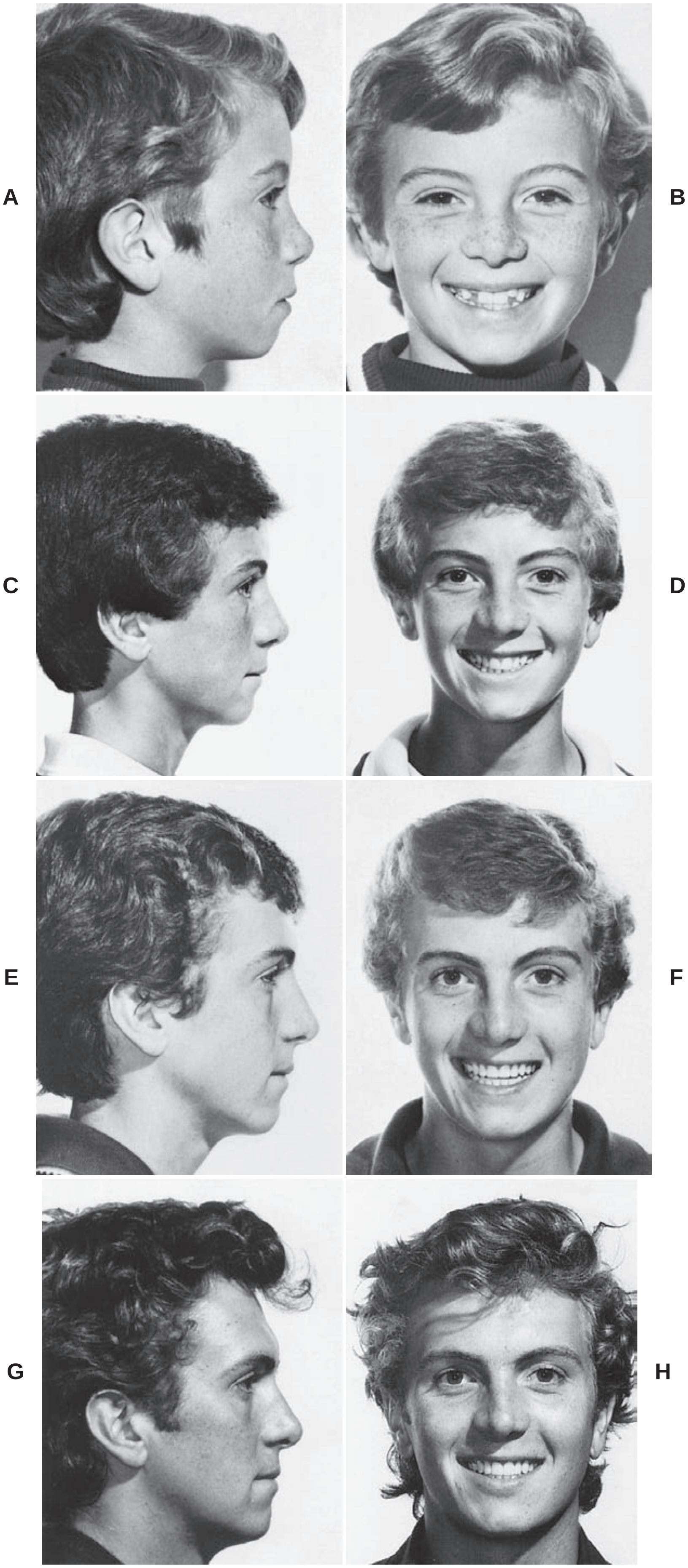

FIGURE 13-87 Facial appearance of patient M.R. Before **(A, B)** and after **(C, D)** serial extraction. **E, F,** After the fixed appliance treatment. **G, H,** Fifteen years after treatment. Cephalometric analysis of M.R.

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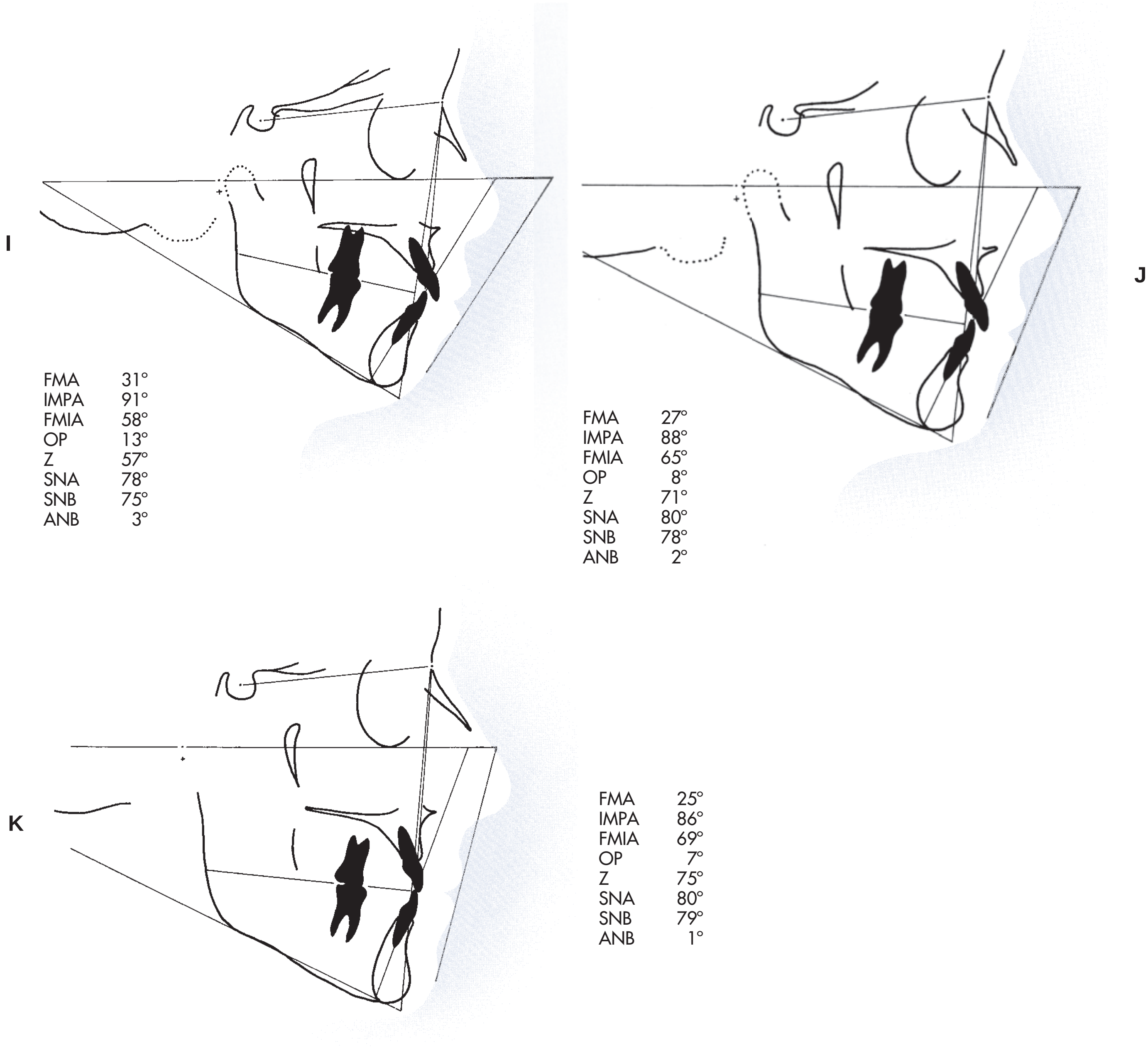

I

FMA	31°
IMPA	91°
FMIA	58°
OP	13°
Z	57°
SNA	78°
SNB	75°
ANB	3°

J

FMA	27°
IMPA	88°
FMIA	65°
OP	8°
Z	71°
SNA	80°
SNB	78°
ANB	2°

K

FMA	25°
IMPA	86°
FMIA	69°
OP	7°
Z	75°
SNA	80°
SNB	79°
ANB	1°

FIGURE 13-87, cont'd **I,** Before serial extraction. **J,** After serial extraction. **K,** After fixed appliance treatment.

treatment—superimposition of cephalometric tracings 4 and 5 (Figure 13-86, *J*).

Figure 13-86, *K*, illustrates the response during the total treatment: interceptive guidance and edgewise appliance. The mandibular incisors gradually move upright, reducing the alveolar dental protrusion; the mandibular molars move upward and forward, accounting for an upward and forward rotation of the mandible.

Figure 13-87 presents the facial appearance before and after serial extraction and fixed appliance treatment. Note that this patient before treatment has a moderate high-angle facial pattern and alveolodental protrusion. After treatment the facial configuration exhibits harmony and balance. The smile has improved after serial extraction and again after multibanded treatment. Balance and harmony persist 15 years after treatment.

Before treatment, the cephalometric analysis of patient M.R. showed an FMA of 31 degrees. This represents a high-angle face. Throughout the course of serial extraction the FMA was reduced to 27 degrees and throughout the course of fixed appliance treatment to 25 degrees. The 6-degree reduction indicated a favorable upward and forward rotation of the mandible. The patient's IMPA before treatment was 91 degrees, suggesting a moderate alveolodental protrusion for a high-angle facial pattern. During serial extraction the mandibular incisors were positioned upright to 88 degrees and during active treatment to 86 degrees. This reduction of 5 degrees in the IMPA resulted in a slightly more balanced and harmonious soft tissue profile. The overall increase in the FMIA of 11 degrees (from 58 to 69 degrees) reflected a reduction in the FMA and the IMPA and a favorable rotation of the mandible and correction of the alveolodental protrusion. The reduction of the occlusal plane angle from 13 to 8 degrees during serial extraction indicated a mesial migration of the posterior teeth and an upright positioning of the mandibular incisor teeth, both favorable responses in the treatment of this particular facial pattern. The reduction of the OP angle from 8 to 7 degrees during active treatment indicated good control. The overall increase in the Z angle of 18 degrees (from 57 to 75 degrees) reflected a favorable rotation of the mandible and correction of the alveolodental protrusion. The maxilla grew slightly during the serial extraction period from 78 to 80 degrees and remained relatively constant during active treatment. Mandibular growth and rotation accounted for 3 degrees during the serial extraction period and for one more degree during the active period of treatment. Throughout total treatment the ANB was reduced from 3 degrees to 1 degree, indicating a modest improvement in the jaw relationship (Figure 13-87, *I–K*).

Important in patient M.R.'s case was that the tooth-size/jaw-size discrepancy not be corrected by extension of the teeth posteriorly, anteriorly, laterally, or vertically. If this had been done in such a high-angle facial pattern, the molar extrusion would have resulted in an unfavorable downward and backward rotation of the mandible. With extrusion of the molars and the dumping forward of the incisors, the occlusal plane would have been tipped unfavorably and the alveolodental protrusion worsened. With the mandibular rotation and the tipped occlusal plane, the maxillary incisor would have been rabbited downward and backward, revealing more gingival tissue. Concomitant effects include impaction of the posterior molars and expanded dental arches. Furthermore, the mandibular incisors would have been tipped off basal bone, creating an unstable situation that required prolonged retention. The harmony and balance of the facial profile could have been worsened considerably.[56]

The total space analysis indicated an anterior and posterior space discrepancy. The anterior discrepancy was corrected by serial extraction and extraction of the permanent first premolars. The posterior discrepancy was corrected by extraction of the permanent third molars.

KEY MEASUREMENTS FOR DIAGNOSIS AND CASE EVALUATION

The Tweed Foundation has conducted several studies on the difference between successful and unsuccessful treatment.[57–63] They have indicated six measurements that are crucial in the evaluation of this difference: FMA, ANB, Z angle, OP, SNB, and the ratio of the posterior face height–to–anterior face height ratio (PFH/AFH) (Box 13-1). We have designed a "wiggle" to illustrate successful treatment (Figure 13-88).[14] Patient M.R.'s six measurements before serial extraction (Figure 13-88, *A*) were to the left of the wiggle, in the retrognathic, high-angle vertical growth area: FMA = 31, ANB = 3, Z angle = 57, OP = 13, SNB = 75, and PFH/AFH = 0.65.

After serial extraction (Figure 13-88, *B*), all six measurements were within the normal range: FMA = 27, ANB = 2, Z angle = 71, OP = 8, SNB = 78, and PFH/AFH = 0.69. Clinically, this is a highly successful response, especially without mechanotherapy.

After edgewise treatment (Figure 13-88, *C*), the measurements increased slightly but remained within the normal range, except for one reading, the OP, which was overcorrected slightly.

> *When facial deformity has been corrected and mental anguish eliminated, a dull and unhappy facial expression becomes bright and happy. What greater reward could any orthodontist want or expect?*
>
> *—Charles H. Tweed*

The earlier this beneficial result occurs, the better.

BOX 13-1 Six Crucial Measurements for Treatment Success

FMA (Frankfurt mandibular plane angle) Indicates mandibular response. In most patients successful treatment is associated with a favorable counterclockwise rotation indicated by a reduction of FMA.

ANB (A point–nasion–B point angle) Indicates the correction of a skeletal discrepancy. Successful treatment is associated with a reduction in ANB in most instances.

Z angle Indicates the alveolar dental and soft tissue profile response. With successful treatment, improvement in the soft tissue balance and harmony and reduction in the alveolar dental protrusion occur. This is associated with an increase in the Z angle.

OP (occlusal plane) Indicates the control of treatment. If the mandibular molars are prevented from extruding and the mandibular incisors are not "dumped" forward, the occlusal plane does not tip forward. If anchorage is prepared and the incisors are positioned upright, the OP decreases. Successful treatment is associated with a flattening of the OP.

SNB Indicates the mandibular response. In most patients if the treatment is successful, the SNB angle will increase.

PFH/AFH (posterior facial height/anterior facial height) Indicates the mandibular response. In successful treatment the PFH increases relatively more than the AFH; therefore the ratio increases.

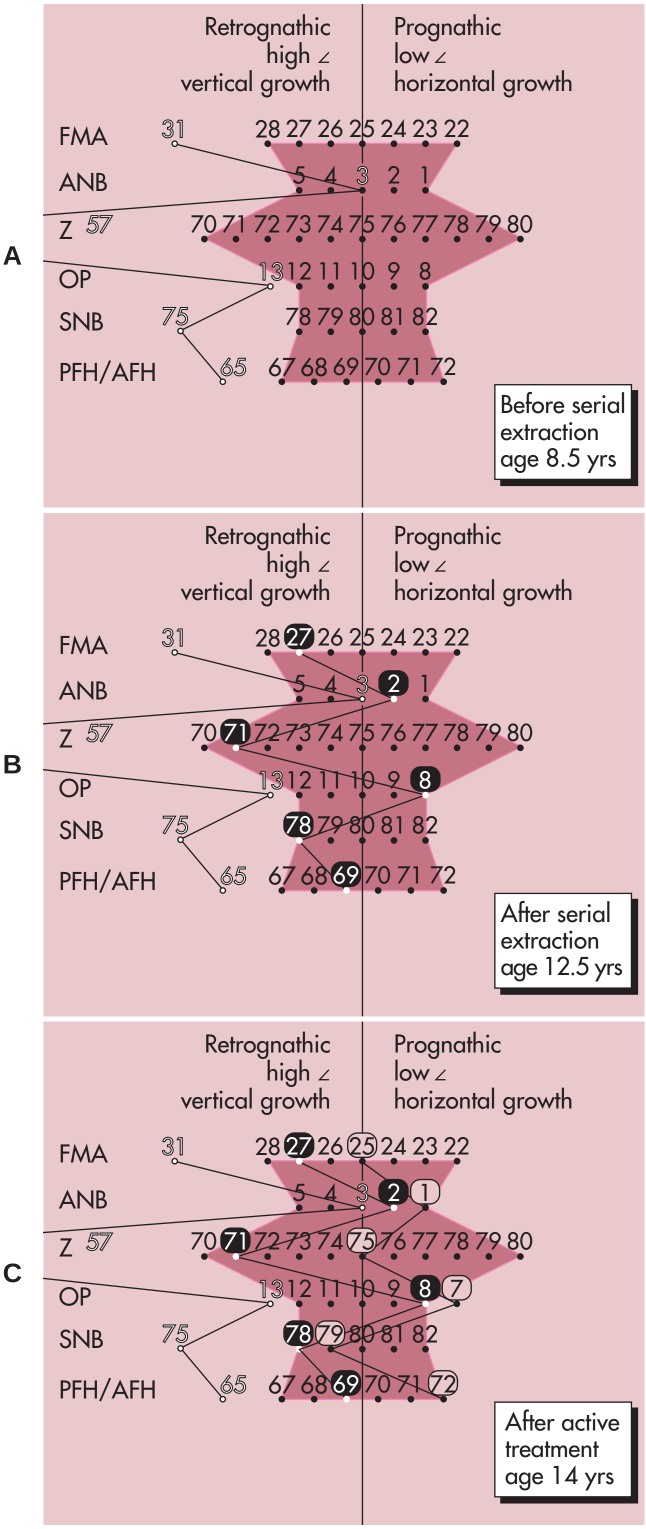

FIGURE 13-88 **A,** The graphic "wiggle" for patient M.R. before serial extraction. **B,** The wiggle for patient M.R. after serial extraction. **C,** The combined graphic wiggle for patient M.R. Note the improved measurements after both serial extraction and fixed appliances.

Acknowledgment

The concepts behind guided extraction and orthodontic treatment have been developed over a period of time and are reflected herein to be most current. Over the years, there have been a number of "champions" of the technique that worked hard to teach the concepts involved. Dr. Warren R. Mayne, one of the original champions, worked with Dr. Tom Graber and contributed the guided extraction chapter in the first and second editions of this text. Both the authors and the editors recognize his initial contributions. We are all happy to see the concepts underlying guided extraction still relevant for today's clinician.

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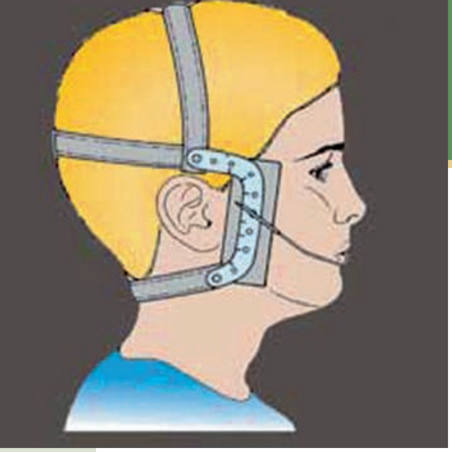

CHAPTER 14

Optimizing Orthodontic and Dentofacial Orthopedic Treatment Timing

James A McNamara, Laurie McNamara, Lee W. Graber

OUTLINE

- **The Timing of Treatment Intervention**
  - Modification of Craniofacial Growth
  - Patient Cooperation
  - Practice Management
- **The Cervical Vertebral Maturation Method**
- **When to Intervene?**
- **Treatment of Tooth Size–Arch Size Discrepancy Problems**
  - Space Maintenance during the Transition of the Dentition
  - Transpalatal Arch
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- **Serial Extraction**
- **Arch Expansion**
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- **Spontaneous Improvement of Sagittal Malocclusions**
  - Class II Patients
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- **The Treatment of Class II Malocclusion**
  - Components of Class II Malocclusion
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- **Treatment of Class III Malocclusion**
  - Components of Class III Malocclusion
  - Appliance Selection
  - Additional Comments Regarding Class III Treatment
- **Summary**

The focus of this chapter is the integration of various orthodontic and orthopedic protocols that can be used to treat the myriad of dentoskeletal problems seen routinely in orthodontic practice. Some malocclusions respond well when orthodontic treatment is begun in the mixed dentition; other conditions are treated optimally at the time of the circumpubertal growth spurt, or even later. The nature of the problem, as determined through the process of proper differential diagnosis and treatment planning, determines whether intervention is best begun *early* (as in the early mixed dentition) or *late* (late mixed or early permanent dentition).

If a *late* treatment is initiated, a single phase of comprehensive orthodontic therapy usually is involved, the duration of which typically spans 2 to 3 years. If treatment begins in the early mixed dentition, however, in most instances a two-phase treatment protocol is anticipated, with a second phase of fixed orthodontic appliances required in the vast majority of such patients. The goal of such early treatment is to correct existing or developing skeletal, dentoalveolar, and muscular imbalances to improve the orofacial environment *before* the eruption of the permanent dentition is complete. By initiating orthodontic and orthopedic treatment at a younger age, the overall need for complex orthodontic treatment involving permanent tooth extraction and orthognathic surgery presumably is reduced.

THE TIMING OF TREATMENT INTERVENTION

A topic of much conversation and debate among orthodontists and even the lay public has been orthodontic treatment timing, with articles concerning this subject appearing not only in refereed orthodontic journals but also in such publications as *The New York Times*, *The*

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Wall Street Journal, and *US News and World Report* during the past decade. These articles reflect one of the dilemmas facing the practicing orthodontist—whether to intervene before the eruption of the permanent dentition is complete.

One can argue that in many patients it is best to allow for the eruption of all permanent teeth (except for third molars) before initiating orthodontic treatment. By having all teeth erupted fully, treatment often is provided in a relatively straightforward manner within a predictable period of time (e.g., 24 to 36 months). When dealing with the postpubescent patient in whom most growth has terminated, the clinician usually does not have to contend with unwanted changes associated with aberrant growth patterns. In fact, in some types of malocclusions, as, for example, in a Class III malocclusion characterized by mandibular prognathism, definitive orthodontic and surgical treatment is best deferred until the end of the active growth period.

Although deferring treatment of orthodontic problems to the adolescent age period is viewed as an advantage by some clinicians, others view it as a significant disadvantage. Many clinicians seek to intervene in the mixed dentition so as to eliminate or modify skeletal, muscular, and dentoalveolar abnormalities before the eruption of the permanent dentition occurs. On the surface, this concept seems reasonable, because it appears more logical to prevent an abnormality from occurring than to wait until it has become developed fully. Not all clinicians, however, employ early treatment protocols. The decision concerning whether to intervene before the eruption of the permanent dentition can be viewed on the basis of a number of interactive factors.

Modification of Craniofacial Growth

The name of the *American Journal of Orthodontics* was changed by then Editor-in-Chief T.M. Graber to the *American Journal of Orthodontics and Dentofacial Orthopedics* in 1985. Ten years later, the orthodontic specialty changed its name from *Orthodontics* to *Orthodontics and Dentofacial Orthopedics*. Both of these changes in designation are a reflection of the importance now given to the orthopedic aspect of orthodontics. Despite this change in emphasis, however, the role of dentofacial orthopedics remains controversial.

During the past 40 years, there has been much discussion among orthodontists and craniofacial biologists regarding the extent and location of therapeutically induced neuromuscular and skeletal adaptations throughout the craniofacial complex. Most would agree that the downward and forward growth of the maxillary complex of the growing individual can be influenced by such therapeutic techniques as extraoral traction and activator therapy. The ability to widen the transverse dimension of the maxilla through rapid maxillary expansion (RME) no longer is considered particularly controversial, although the long-term stability of this form of treatment only recently has been evaluated thoroughly.

The question of whether the mandible can be increased in length in comparison with untreated controls also has been addressed in numerous experimental and clinical studies (for a review of the literature in this area, see Chapter 15 in McNamara and Brudon[1]). Although controversial, the bulk of scientific evidence indicates that, in growing individuals, mandibular growth can be enhanced over the short term. A recent study of long-term functional jaw orthopedics (FJO) by Freeman and coworkers[2] that considered the long-term effect of the function regulator (FR-2) of Fränkel showed that in late adolescence the average increase in mandibular growth in the treatment group was 3 mm (but only 3 mm, not more) in comparison with matched untreated Class II subjects. Other long-term studies have shown residual mandibular length increases in the range of only 1 to 2 mm,[3,4] with only one other study reporting a long-term 5-mm increase in comparison with untreated Class II controls.[5]

In contrast, there is limited evidence that the growth of the mandible can be diminished substantially,[6] either through the use of a chin cup or through orthopedic facial mask therapy, although a redirection of mandibular growth in a more vertical direction has been observed using a number of orthopedic techniques.[7]

Patient Cooperation

The “Achilles heel” of many early treatment protocols is patient cooperation.[8] The ability to motivate a patient to comply is an essential ingredient of successful orthodontic therapy, whether initiated in the mixed or permanent dentition. One of the great fears of many orthodontists is that by beginning treatment in the mixed dentition, patient and parental cooperation will wane before fixed appliance therapy has been completed to the clinician’s satisfaction. The goals and objectives of treatment must be established clearly in order to prevent unnecessary, prolonged treatment that may “burn out” the patient in the future.

In our opinion, the most significant problem regarding cooperation, particularly in the mixed dentition patient, is in the mind of the orthodontist or the parent rather than in the mind of the young patient. Every effort must be made to incorporate the patient and parent in the treatment decision and to stress the importance of appliance wear according to the specific needs of the patient. Indeed, motivating parents to provide the home support necessary for treatments that require strict compliance is often the greatest challenge to the clinician as parents look for quick solutions to even complex treatment challenges. Regimens requiring maximal patient cooperation should be used only after it has been determined that this type of appliance is the optimal approach for a given skeletal and neuromuscular imbalance. The treatment time should be estimated reasonably and should be known to the patient and parent at the beginning of the treatment period.

A critical point in patient cooperation is related to the transition to high school, with the start of ninth grade often coinciding with a decrease in patient motivation. Thus, it is desirable to complete either Phase II treatment or a comprehensive single-phase treatment prior to this time. It has been our experience that most patients who begin orthodontic or orthopedic treatment in the second or third grade finish Phase II prior to high school, although there is substantial individual variation. Scheduling of orthodontic appointments also is much easier during middle school or junior high school years than later.

Practice Management

It is obvious that when patients begin treatment in the mixed dentition, the time from the onset of treatment to the completion of the final fixed appliance phase will extend well beyond the duration of a typical orthodontic protocol initiated in the early permanent dentition. When many of the currently used early treatment protocols were being developed in the late 1970s and early 1980s, there were many instances of prolonged treatments that not only had a negative effect on patient and parental enthusiasm but also became a nightmare from a practice management perspective. Thus, more efficient early treatment protocols have evolved. These protocols have a defined duration as well as a reasonably predictable outcome.

In general terms, an initial phase of treatment is provided that is approximately 1 year in duration, followed by intermittent observation during the transition from the mixed to the permanent dentition. The naturally occurring increases in arch space are incorporated into the overall treatment plan by anchoring the permanent first molars in position as the second deciduous molars are lost, usually by placing a transpalatal arch (TPA) in the maxilla and, in about one third of patients, a lingual arch in the mandible. After all of the permanent teeth have erupted fully into occlusion (except for, perhaps, the second and third molars), fixed appliances then are used to align and fine detail the occlusion. Treatment typically is not begun until the eruption of the second molars has taken place or is anticipated within a 6- to 9-month period.

From a practice management perspective, separate charges are levied for the initial phase of early treatment and for the final comprehensive phase of treatment. In our practices, no charges are levied for appointments during the "interim" period when the eruption of the permanent dentition is monitored two or three times a year. These visits are important to monitor any spaceholding appliances and are extremely valuable to ensure proper timing for full fixed appliance treatment.

THE CERVICAL VERTEBRAL MATURATION METHOD

Before we begin a detailed description of the protocols that can be used to treat various malocclusion types, a discussion of the skeletal maturational level of the patient is in order. In some instances, it is desirable to treat the patient at the time when the patient is growing rapidly, as during the circumpubertal growth period, when functional jaw orthopedics has been shown to be particularly effective. In other circumstances, we would like to know if a patient has reached his or her growth potential, as in planning corrective jaw surgery or the placement of endosseous implants, so that substantial further growth is not anticipated or desired. We also would like to know if a patient is early in the growth process and would respond skeletally rather than dentally to forces placed against the circummaxillary sutural system (e.g., RME, facial mask therapy).

One of the most *inaccurate* ways of determining a patient's maturational level is to use chronologic age as an indicator. It is well known that in a classroom of 10-year-old children, there may be as much as a 7-year spread developmentally among the children, with females maturing faster than males on average by at least a year. On the other hand, orthodontists in general have relied on the stage of dental eruption and development[9,10] as a starting point. This scheme of using tooth eruption as an indicator certainly is more accurate that using chronologic age. However, other biological indicators can be used as well.

Biological indicators of skeletal maturity refer mainly to somatic changes at puberty, thus emphasizing the known interactions between the development of craniofacial structures and the modifications in other body regions. Individual skeletal maturity can be assessed by means of several biological indicators, including increase in body height,[11–13] skeletal maturation of the hand and wrist,[9,14] menarche or voice changes,[15,16] as well by changes in the morphology of the cervical vertebrae.[17,18]

Of the skeletal indicators available routinely to the orthodontic practitioner that do not require the taking of additional records (e.g., hand-wrist film), the cervical vertebral maturation (CVM) method has proved clinically useful for us for over a decade. This method has been available since the early 1970s when it was developed by Don Lamparski as part of his master's of science thesis at the University of Pittsburgh.[17] The CVM method remained relatively unknown for the next 25 years, with few references made to it in the literature.[18,19] The CVM method was reintroduced by our group first in 2000, with the current modified version presented in 2005.[20] The following is a brief summary of the method.

There are six stages of cervical maturation in all, as is shown diagrammatically in Figure 14-1. For the purpose of this evaluation using the lateral headfilm,

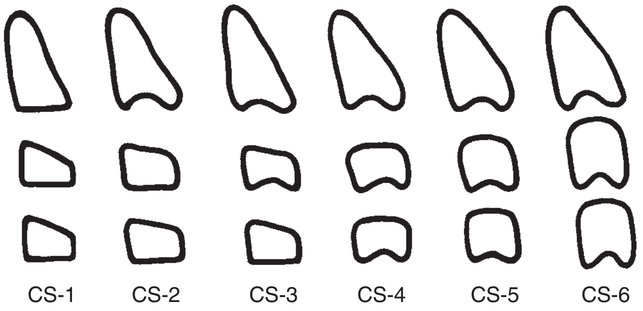

FIGURE 14-1 Schematic representation of the six stages of cervical vertebral maturation, according to the protocol described by Baccetti and co-workers.[20] The second, third, and fourth cervical bodies are shown. Note the increase in notching and the changes in the shape of the third and fourth cervical bodies with maturation.

only the bodies of the second, third, and fourth cervical vertebrae (C2, C3, and C4) are considered. Two morphologic characteristics are monitored, the first of which is the presence or absence of a notch or indentation on the inferior border of each of the three vertebral bodies. The second feature is the shape of the third and fourth cervical bodies, which vary from trapezoid to rectangular horizontal to square to rectangular vertical (Figure 14-1).

The first three stages are differentiated by the presence or absence of the notch. In the first cervical stage (CS-1), the inferior borders of vertebral bodies 2 to 4 are flat (or sometimes slightly convex) (Figure 14-2). From a practical standpoint, the notch must be at least 1 mm in depth at the center in comparison with the anterior and posterior aspects of the inferior border of the body. The third and fourth cervical bodies are trapezoidal in morphology, assuming the shape of a wedge or "ski jump," with the posterior border of the vertebral body taller than the anterior border and the superior surface sloping forward and downward. This stage occurs from approximately the time of the eruption of the deciduous dentition until about 2 years before the peak in skeletal growth. Our research[21] has shown that the ideal age to intervene with facial mask (FM) therapy combined with RME is at CS-1. Maximum skeletal adaptations occur in the midfacial region during this stage. Less skeletal and greater dentoalveolar adaptations are noted when RME+FM therapy are used during later stages (e.g., CS-3, CS-4).

The second cervical stage (CS-2) is characterized by a notch present along the inferior border of the second cervical vertebra (odontoid process). The lower borders of the third and fourth vertebral bodies remain flat (Figure 14-3). Usually both C3 and C4 retain a trapezoidal shape. CS-2 can be termed the "get-ready" stage because the peak interval will begin about 1 year after this stage is evident.

The third cervical stage (CS-3) is characterized by notching of the inferior borders of C2 and C3. C4 remains flat (Figure 14-4). At least one of C3 and C4 bodies still retains a trapezoidal shape while the other can assume a more rectangular horizontal shape. At this stage the maximum craniofacial growth velocity is anticipated. It must be remembered that the difference between stages is gradual, not abrupt, so that saying that someone is a "late CS-3" or an "early CS-4" is appropriate, depending on the transitional morphology of the third and fourth vertebrae.

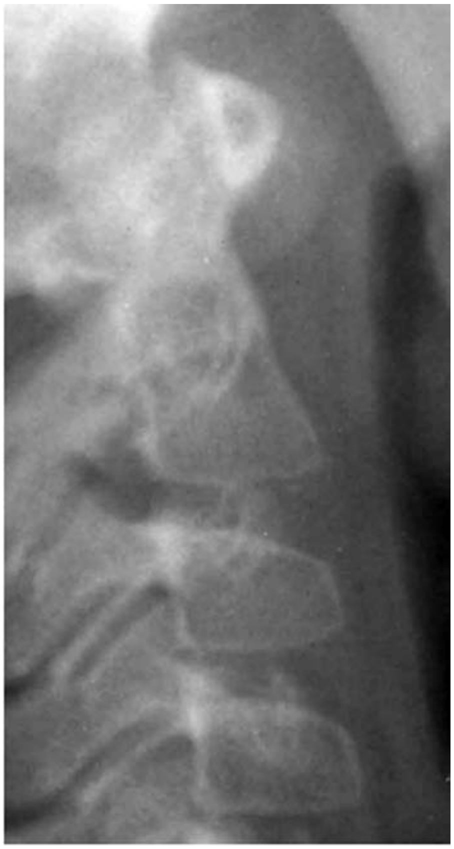

FIGURE 14-2 The first CVM stage (CS-1). Note that the inferior borders of the three cervical bodies are not indented but are flat or slightly convex.

In the fourth cervical stage (CS-4), all three bodies have notches along their inferior bodies, so the more important factor is the shape of C3 and C4 (Figure 14-5). At this stage, both vertebral bodies have a rectangular horizontal rather than a trapezoidal shape. It is easiest to remember this stage as the "bar of soap" stage because the bodies of both C3 and C4 assume this well-known shape (Figure 14-6). During this stage, continued craniofacial growth can be anticipated, but at a lesser rate than is seen at CS-3. Placing an endosseous implant to replace a missing maxillary lateral incisor would be inappropriate at this stage of maturation.

The fifth cervical stage (CS-5) can be differentiated from CS-4 on the basis of the shapes of C3 and C4, with these bodies becoming square in shape (Figure 14-7). All three cervical bodies have notches, so the presence of notching no longer is important in the differential

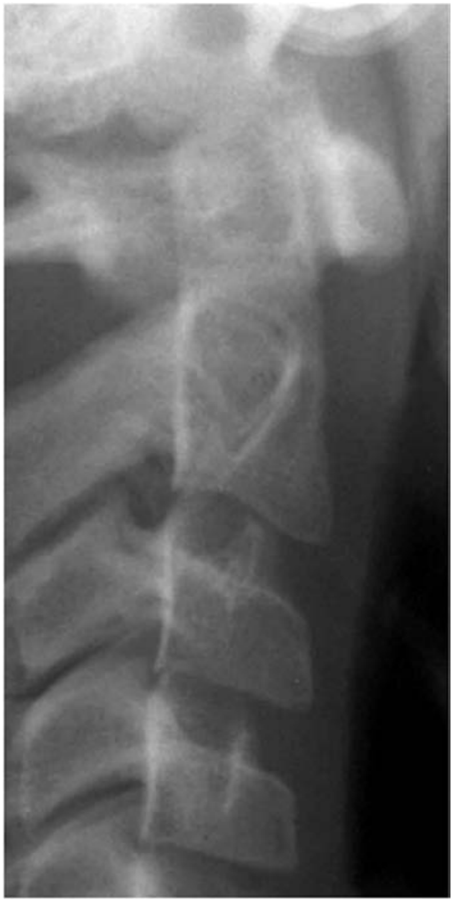

FIGURE 14-3 The second CVM stage (CS-2). A notch is present in the inferior border of the odontoid process (C2). The vertebral bodies of C3 and C4 are in the shape of a wedge or trapezoid.

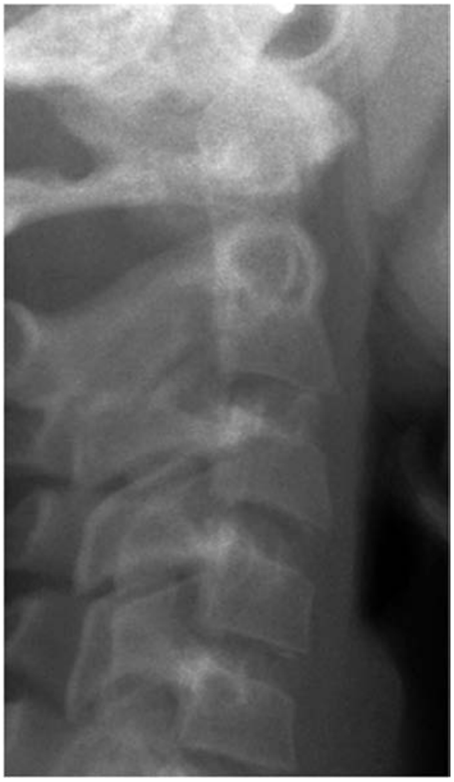

FIGURE 14-4 The third CVM stage (CS-3). Distinct notches are present on the inferior border of C2 and C3. C4 still has a trapezoidal shape.

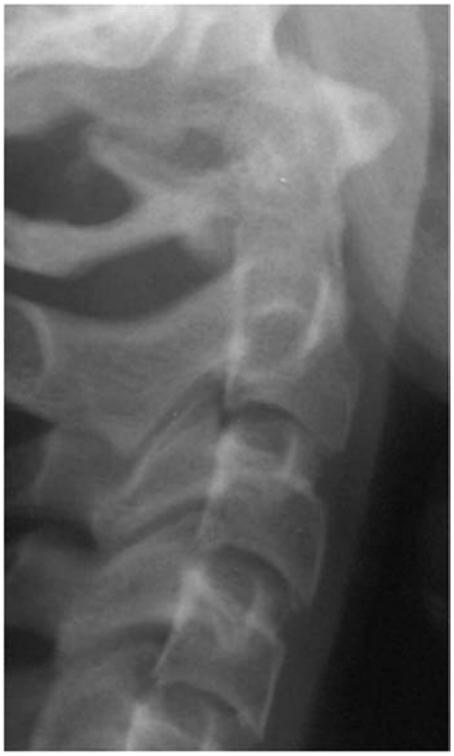

FIGURE 14-5 The fourth CVM stage (CS-4). Notches are present in all vertebrae. The bodies of C3 and C4 are rectangular horizontal in shape.

diagnosis. We have found it easy to remember this stage as the “marshmallow” stage, in that the bodies now resemble the soft white puffy confection seen so commonly at summer campfires (Figure 14-8). When this stage is reached, most substantial craniofacial growth has been achieved. The patient can be evaluated for corrective jaw surgery or the placement of endosseous implants. It should be noted that even though CVM staging is useful here, the gold standard for determining the continuation or cessation of significant craniofacial growth is the evaluation of two lateral headfilms taken at least 6 months apart.

It has been our experience that the most difficult stage to determine is the sixth cervical stage (CS-6). At CS-6, at least one of the third and fourth cervical bodies has assumed a rectangular vertical morphology (Figure 14-9). In addition, the cortical bone appears better defined in CS-6. Of course, the age of the patient is known, so anyone over the age of 20 years presumably would be at CS-6.

Estimating the maturational level of the patient by staging the second through fourth cervical vertebral bodies gives the clinician one additional piece of information that can be used to reach an appropriate

FIGURE 14-6 The vertebral bodies of C3 and C4 at CS-4 resemble the shape of an ordinary bar of soap, as is shown here.

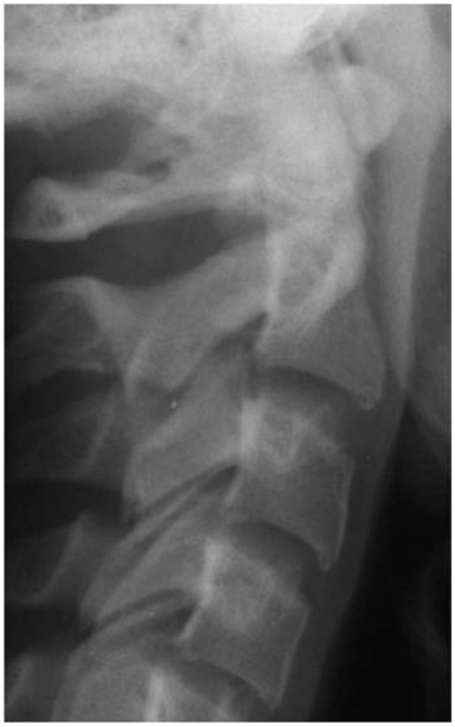

FIGURE 14-7 The fifth CVM stage (CS-5). The bodies of C3 and C4 now are square in shape.

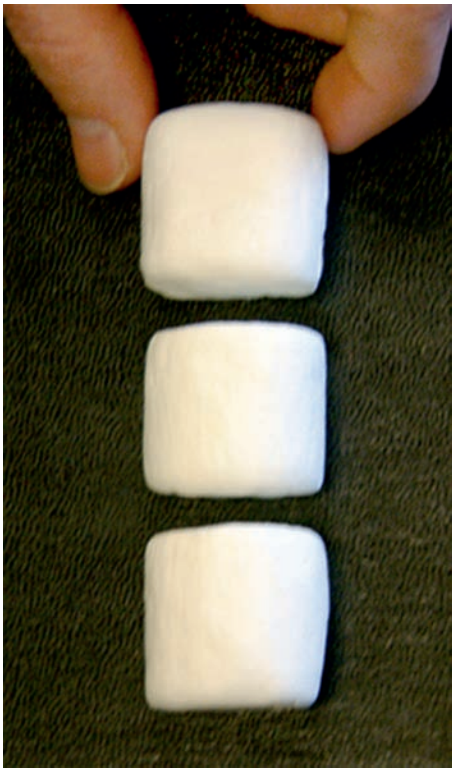

FIGURE 14-8 C3 and C4 at CS-5 resemble the shape of a stack of marshmallows, as imaged here.

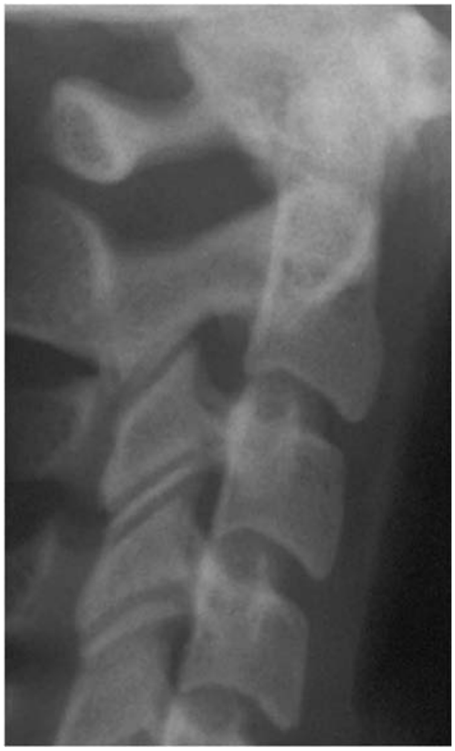

FIGURE 14-9 The sixth CVM stage (CS-6). The bodies of C3 and C4 now are rectangular vertical in shape (i.e., greater height than width). Eccentric notching of the inferior border and vaulting of the superior border is distinct.

diagnosis and treatment. CVM staging should be used in concert with a thorough evaluation of the hard and soft tissue during the treatment planning process. As with any subjective clinical evaluation, the precision of the CVM method improves with practice.

WHEN TO INTERVENE?

The timing of orthodontic intervention is of critical importance, and the initiation of our treatment protocols varies according to the type of malocclusion being treated. For example, tooth size–arch size discrepancy problems typically are treated when the patient is 8 or 9 years of age. Normally, this treatment is initiated after the lower four incisors and the upper central incisors have erupted. In many instances, there is insufficient space to allow for the unimpeded eruption of the upper lateral incisors. Depending on the size of the permanent teeth, space maintenance, serial extraction, orthopedic expansion, or a combination of these protocols is used.

In the instance of a Class III malocclusion, the onset of treatment is usually earlier than for the Class I patient. An optimal time for the beginning of an early Class III treatment regimen (e.g., orthopedic facial mask combined with a bonded acrylic splint expander to which have been attached facial mask hooks) is coincident with the loss of the upper deciduous incisors and the eruption of the upper permanent central incisors (the maxillary permanent first molars should be erupted as well). This earlier intervention in Class III patients obviously will result in a longer period of time between the start of the initial phase of treatment and the end of the fixed appliance phase after the permanent dentition has erupted. Also, as will be discussed later, the early treatment of Class III malocclusions may be characterized by more than one period of intervention during the mixed dentition.

The timing of treatment of Class II malocclusions differs substantially from that described previously for Class I and Class III malocclusions. In contrast to our positive recommendations concerning early intervention in Class III malocclusions and in many tooth size–arch size discrepancy problems, we typically recommend a delay until the circumpubertal growth period (i.e., cervical stage CS-3) before using functional jaw orthopedics in patients with Class II malocclusions characterized in part by mandibular skeletal retrusion. Both clinical and experimental studies have shown that there is a greater mandibular growth response with functional appliances when treatment is initiated during the circumpubertal growth period.[22–24] Ideally, functional appliance therapy (e.g., Herbst®, twin block, MARA, bionator, FR-2 of Fränkel) will be followed directly by a phase of fixed appliance therapy to align the permanent dentition. In reality, besides the routine use of Class II intermaxillary elastics, we use two Class II correction appliances primarily, both in the early permanent dentition. These two appliances are the stainless steel crown Herbst appliance and the Pendex appliance.

In patients who present with severe neuromuscular and skeletal problems that lead to what we have termed “socially debilitating” malocclusions, though, the initiation of treatment earlier in the mixed dentition sometimes is indicated. From a physiologic standpoint, it may be better to delay treatment until the circumpubertal growth period so that a maximum response to functional jaw orthopedics can be achieved. However, earlier intervention may be necessitated due to psychological issues related to the underlying severity of the malocclusion.[25,26] Fortunately, such “socially debilitating” malocclusions are not observed frequently.

In Class II patients who present with maxillary prognathism, the timing of treatment does not appear to be crucial. Extraoral traction can be used in either the mixed or permanent dentition to treat this type of skeletal imbalance satisfactorily.[27–32]

It also should be noted that in many patients with Class II malocclusions identified in the 7- to 9-year-old age range, treatment is initiated at that time to handle intra-arch problems (e.g., crowding, spacing, flaring). Interarch discrepancies are addressed later. In other words, the same protocols (e.g., orthopedic expansion, extractions) that can be used for Class I patients may be initiated in Class II patients with arch length discrepancies. The attempt to correct mandibular deficiency, however, often is best delayed until near the circumpubertal growth period in patients with mild to moderate sagittal problems.

TREATMENT OF TOOTH SIZE–ARCH SIZE DISCREPANCY PROBLEMS

The most common type of malocclusion noted in the mixed dentition usually is described as “crowding.” These patients are referred by the general dentist or by the patient’s parents because of obvious dentoalveolar protrusion or lack of sufficient space for permanent tooth eruption. Most commonly, this type of patient presents with a Class I molar relationship or a tendency toward either a Class II or Class III malocclusion.

In the permanent dentition, discrepancies between tooth size and arch size usually are handled by one of three treatment modalities: extraction,[33–37] interproximal reduction,[38–43] or arch expansion.[44–50] Comparable treatment protocols in the mixed dentition are serial extraction and orthopedic expansion, with interproximal reduction usually being reserved for permanent dentition patients only. Additional methods of treating discrepancy problems in the mixed dentition that are not available for use in permanent dentition patients include techniques of space management (e.g., maintenance of leeway space).

Space Maintenance during the Transition of the Dentition

An integral part of any mixed dentition protocol is monitoring the transition from the mixed to the permanent dentition. Significant differences exist between the sizes of the second deciduous molars and the succeeding second premolars.[51] On average, 2.5 mm per side of arch space can be gained in the mandibular arch, and about 2 mm per side can be gained in the maxillary arch. There is wide variation in tooth size among patients,[52] however, and thus each patient must be evaluated radiographically to determine the relative size of the second deciduous molars and their successors. Simply maintaining available arch space during the transition of the dentition may be sufficient to resolve minor to moderate tooth size–arch size discrepancies,[53] particularly if judicious interproximal reduction is used after the permanent dentition has erupted.

Two types of arches are used as holding appliances in the late transition of the dentition: the TPA and the lingual arch. These arches routinely are cemented in place prior to the loss of the second deciduous molars.

Transpalatal Arch

The TPA,[1] as the name implies, extends from one maxillary first molar along the contour of the palate to the molar on the opposite side (Figure 14-10). Although both fixed and removable types of TPAs are available, we routinely use the soldered TPA that is made from 0.036-inch stainless steel wire and that is soldered to the molar bands at their mesiolingual line angles. Lingual extensions to the primary cuspids are often used if no molar rotation is needed and/or post-RME treatment.

The major function of the TPA in the mixed dentition is to prevent the mesial migration of the upper first molars during the transition from the second deciduous molars to the second premolars. If desired, this appliance also is capable of producing molar rotations and changes in root torque[54,55] by sequential unilateral activation of the appliance.[56] The TPA also can be used for stabilization of molar position. The TPA routinely is left in place until the final comprehensive phase of orthodontic therapy is completed. Interestingly, the TPA does not function well as an anchorage appliance in extraction cases.[57]

Lingual Arch

The lingual arch, usually used in the mandible as part of our early treatment protocol, has a similar function to the TPA in the maxilla, which is as a molar anchorage appliance. The lingual arch, also made of 0.036-inch stainless steel, extends along the lingual contour of the mandibular dentition from the first molar on one side to the first molar on the other (Figure 14-11). Optional adjustment loops (not shown) can be placed in the lingual arch in the region of the second deciduous molars, providing added ability to adjust arch vertical position and size.

The lower lingual arch is used less frequently than the TPA because there are many patients undergoing early orthodontic treatment who do not require the maintenance of arch space in the second premolar region. Thus, the lower lingual arch is indicated only in patients in whom maximum molar anchorage is to be maintained. Typically, the lower lingual arch is used in about a third of patients undergoing Phase I treatment. In contrast to the TPA, the lingual arch usually is removed after the eruption of the second premolars is completed and the proper positioning of these teeth has been achieved.

Not only is the lingual arch used in Class I individuals in whom arch space is to be stabilized, but also in the treatment of patients with Class III malocclusions. In this instance, molar position is maintained in order to prevent the forward movement of the molars (thus aggravating the Class III molar relationship) and facilitating the more posterior eruption of the mandibular premolars.

SERIAL EXTRACTION

Another protocol that frequently is used in the treatment of tooth size–arch size discrepancies is serial extraction. This early treatment technique involves the sequential

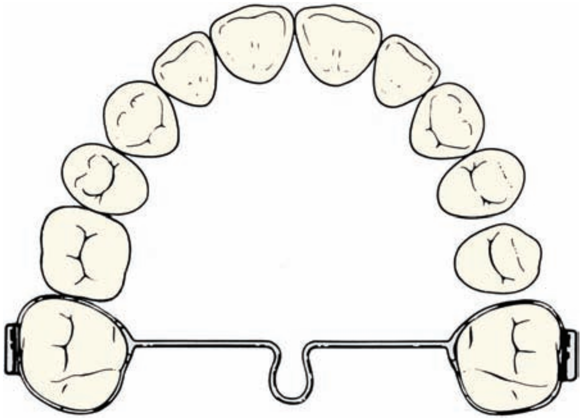

FIGURE 14-10 Transpalatal arch. This arch can be used as both an active appliance and a stabilization appliance during the transition of the dentition. Note the net increase in available space following the transition from the second deciduous molar to the second premolar. *(Adapted from McNamara and Brudon.[1])*

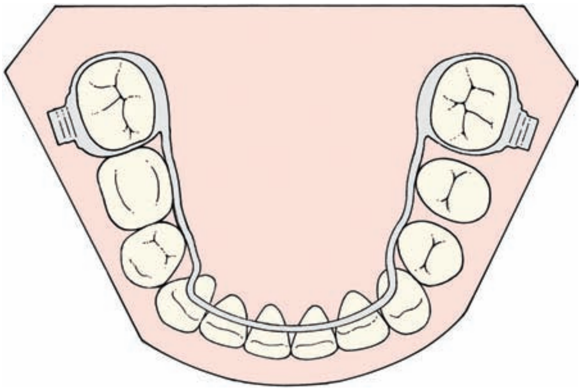

FIGURE 14-11 Lower lingual arch. Note the maintenance of arch space following the loss of the second deciduous molar and the eruption of the second premolar on the left side. Adjustment loops can be placed in the arch in the second premolar region, if desired. *(Adapted from McNamara and Brudon.[1])*

removal of deciduous teeth to facilitate the unimpeded eruption of the permanent teeth. Such a procedure often, but not always, results in the extraction of four premolar teeth. This protocol began in Europe in the 1930s and has been advocated by a number of individuals, including Hotz,[58,59] Kjellgren,[60] Terwilliger,[61] Lloyd,[62] and Palsson.[63] The sequence of serial extraction has been clarified further in a series of articles by Dewel,[64–66] as well as in chapters on this topic by Graber,[67] Proffit,[68] Moyers,[69] and Dale.[70,71] (See Chapter 13.)

Graber[67] states that serial extraction may be indicated when it is determined "with a fair degree of certainty that there will not be enough space in the jaws to accommodate all the permanent teeth in their proper alignment." Proffit[68] cites a predicted tooth size–arch size discrepancy of 10 mm or greater as an indication for serial extraction, whereas Ringenberg[72] mentions a discrepancy of 7 mm or more. In many serial extraction patients, a TPA is used to maintain maxillary molar position as the transition to the permanent dentition occurs.

From our perspective, the primary factor to be evaluated when making a treatment decision concerning serial extraction is *large tooth size*. In instances in which tooth sizes are abnormally large (e.g., maxillary central incisor width >10.0 mm), the initiation of serial extraction protocols may be appropriate. Another factor that must be considered is the anteroposterior positioning of the lower incisors relative to the adjacent skeletal elements as well as to the soft tissue, especially the lip musculature. Serial extraction in crowded patients with extreme bialveolar retrusion and flat facial profiles obviously is not recommended due to potential unfavorable facial contour changes. In fact, mild residual crowding of the lower incisors is more preferable to creating a "dished-in" facial appearance. Similarly, a serial extraction protocol in patients with bialveolar protrusion also is not indicated, because maximum retraction of the incisors is desirable and is not attainable with serial extraction. Maximum anchorage mechanics using fixed appliance therapy[73] (perhaps combined with temporary anchorage devices[74]) usually is the treatment of choice.

Serial extraction may be combined with RME in certain patients with significant arch length discrepancy problems who also present with a narrow tapered maxilla and "negative space"[75] present in the corners of the mouth during smiling. The use of RME is particularly appropriate in patients with broad facial contours. The arches can be expanded first to "broaden" the smile, and then after reevaluation, serial extraction procedures may be initiated subsequently to reduce or eliminate emerging tooth–arch imbalances.

It is well known that serial extraction is not a panacea in all patients who present with dental crowding in the mixed dentition.[72] Great care must be taken to avoid lingual tipping of the lower incisors as well as unfavorable changes in the sagittal position of the upper and lower dentitions. In addition, the initiation of serial extraction procedures may result in unwanted spacing in the dental arches. When used appropriately, however, a protocol of sequentially extracting the deciduous dentition has proven to be an efficient, cost-effective, and satisfactory treatment for tooth size–arch size discrepancy problems.

ARCH EXPANSION

Types of Expansion

It is well known that expansion of the dental arches can be produced by a variety of orthodontic treatments including those that incorporate fixed appliances. The types of expansion produced can be divided arbitrarily into three categories.

Orthodontic Expansion. Orthodontic expansion, produced by conventional fixed appliances as well as by various removable expansion plate and finger spring appliances, usually results in lateral movements of the buccal segments that primarily are dentoalveolar in nature. There is a tendency toward a lateral tipping of the crowns of the involved teeth and a resultant lingual tipping of the roots. The resistance of the cheek musculature and other soft tissue still remains, providing forces that may lead to a relapse or rebound of the achieved orthodontic expansion.[76,77]

Passive Expansion. When the forces of the buccal and labial musculature are shielded from the occlusion, as with the FR-2 appliance of Fränkel,[78] a widening of the dental arches often occurs. This "passive" expansion is not a result of the application of extrinsic biomechanical forces but rather by intrinsic forces such as those produced by the tongue. Brieden and collaborators,[79] in an implant study conducted in patients treated with the FR-2 appliance of Fränkel, have demonstrated that bone deposition occurs primarily along the lateral aspect of the alveolus rather than at the midpalatal suture. A related type of spontaneous arch expansion also has been observed following lip-bumper therapy.[80,81]

Orthopedic Expansion. RME appliances (Figure 14-12) are the best examples of true orthopedic expansion, in that changes are produced primarily in the underlying skeletal structures rather than by the movement of teeth through alveolar bone.[44,47,48] RME not only separates the midpalatal suture but also affects the circumzygomatic and circummaxillary sutural systems.[82] After the palate has been widened, new bone is deposited in the area of expansion so that the integrity of the midpalatal suture usually is reestablished within 3 to 6 months.[45]

Rationale for Early Orthopedic Expansion

The cornerstone of the early orthopedic expansion protocol used in the treatment of patients with arch length discrepancy problems is RME. The use of this expansion

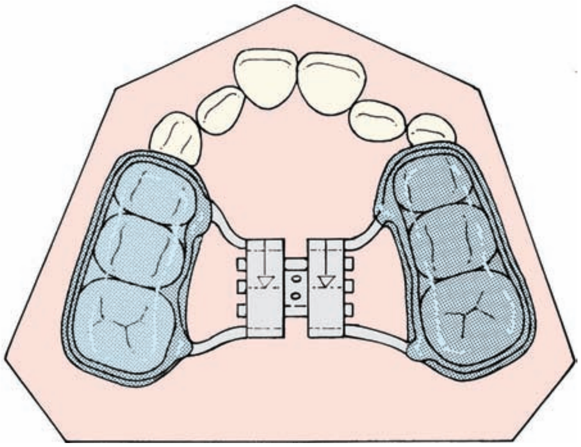

FIGURE 14-12 An acrylic splint RME appliance that is bonded to the maxillary primary molars and the permanent first molars. The occlusal coverage of acrylic produces a posterior bite block effect on the vertical dimension. *(Adapted from McNamara and Brudon.[1])*

protocol is based in part on our previous studies of the development of the dental arches in untreated individuals, both in the permanent dentition and the mixed dentition.[1,51,83]

Permanent Dentition. Howe and co-workers[83] carried out an investigation in which the dental casts of patients with severe crowding were compared with the dental casts of untreated individuals who were classified as having ideal or near-ideal occlusions. No statistically significant differences in tooth size were noted between the uncrowded and crowded populations, regardless of whether aggregate tooth size or the sizes of individual teeth were considered. In contrast, there were statistically significant differences in arch width and arch perimeter. Maxillary intermolar width was of particular importance as an easily measured clinical indicator. In the noncrowded males, the average distance between the upper first permanent molars, measured at the point of the intersection of the lingual groove at the gingival margin, was about 37 mm, a value that can be compared with a similar measure in the crowded males of 31 mm. Similar but slightly smaller measures and differences were noted in the female sample.[83] Howe and coworkers concluded that a transpalatal width of 35 to 39 mm suggests a bony base of adequate size to accommodate a permanent dentition of average size (of course, a larger aggregate tooth size requires a larger bony base and vice versa).

Mixed Dentition. Because the above study was conducted using data from individuals in the permanent dentition, it did not address the issue of the normal development of the dental arches. This question was considered in a second study[56] that examined the nature of normal changes in maxillary and mandibular transpalatal width from the early mixed dentition to the permanent dentition. Longitudinal changes in an untreated population from 7 to 15 years of age were evaluated. The average increase in transpalatal width between the upper first molars was about 2.5 mm.[1,83,84]

One of the conclusions that can be drawn from the studies cited earlier concerning dental arch development is that by providing some mechanism of widening the bony bases and increasing arch width and perimeter, more space can be obtained for the alignment of the permanent dentition. Of course, the dental arches cannot be expanded ad libitum because of the physiologic limits of the associated hard and soft tissues. It seems reasonable, however, to consider increasing arch size at a young age so that skeletal, dentoalveolar, and muscular adaptations can occur prior to the eruption of the permanent dentition.

Orthopedic Expansion Protocols

Our appliance of choice for use in mixed dentition patients is the bonded acrylic splint expander (see Figure 14-12). This appliance, which incorporates a Hyrax-type screw into a framework made of wire and acrylic, is used to separate the halves of the maxilla. It is widely recognized that maxillary expansion is achieved easily in a growing individual, particularly in individuals in the mixed dentition.[85–87] The acrylic-splint type of appliance that is made from 3-mm-thick, heat-formed Biocryl has the additional advantage of acting as a bite block, due to the thickness of the acrylic that covers the occlusal surfaces of the posterior dentition. The posterior bite block effect of the bonded acrylic splint expander prevents the extrusion of the posterior teeth,[88] a movement often associated with banded RME appliances,[89] thus permitting the use of this type of expander in some patients with steep mandibular planes.

Maxillary Adaptations. The treatment protocol that involves the use of a bonded expander is illustrated by the following example. The morphology of a patient in the mixed dentition with an idealized (e.g., 34 to 35 mm) transpalatal width (Figure 14-13, *A*) can be compared to a patient with a narrow (e.g., 29 mm) transpalatal width (Figure 14-13, *B*). A goal of the orthopedic treatment initiated in the mixed dentition is to reduce the need for extractions in the permanent dentition through the elimination of arch length discrepancies as well as the elimination of bony base imbalances. In instances of restricted transverse dimensions (Figure 14-13, *B*), a bonded RME appliance is placed (Figure 14-13, *C*). The screw of the expander is activated one-quarter turn (90 degrees, 0.20 to 0.25 mm) per day until the lingual cusps of the upper posterior teeth approximate the buccal cusps of the lower posterior teeth. In contrast to Haas,[90] who recommends full opening of the expansion screw to 10.5 to 11.0 mm (an action that often produces a buccal crossbite), we advocate only as much expansion as is feasible while still maintaining contact between the upper and lower posterior teeth.

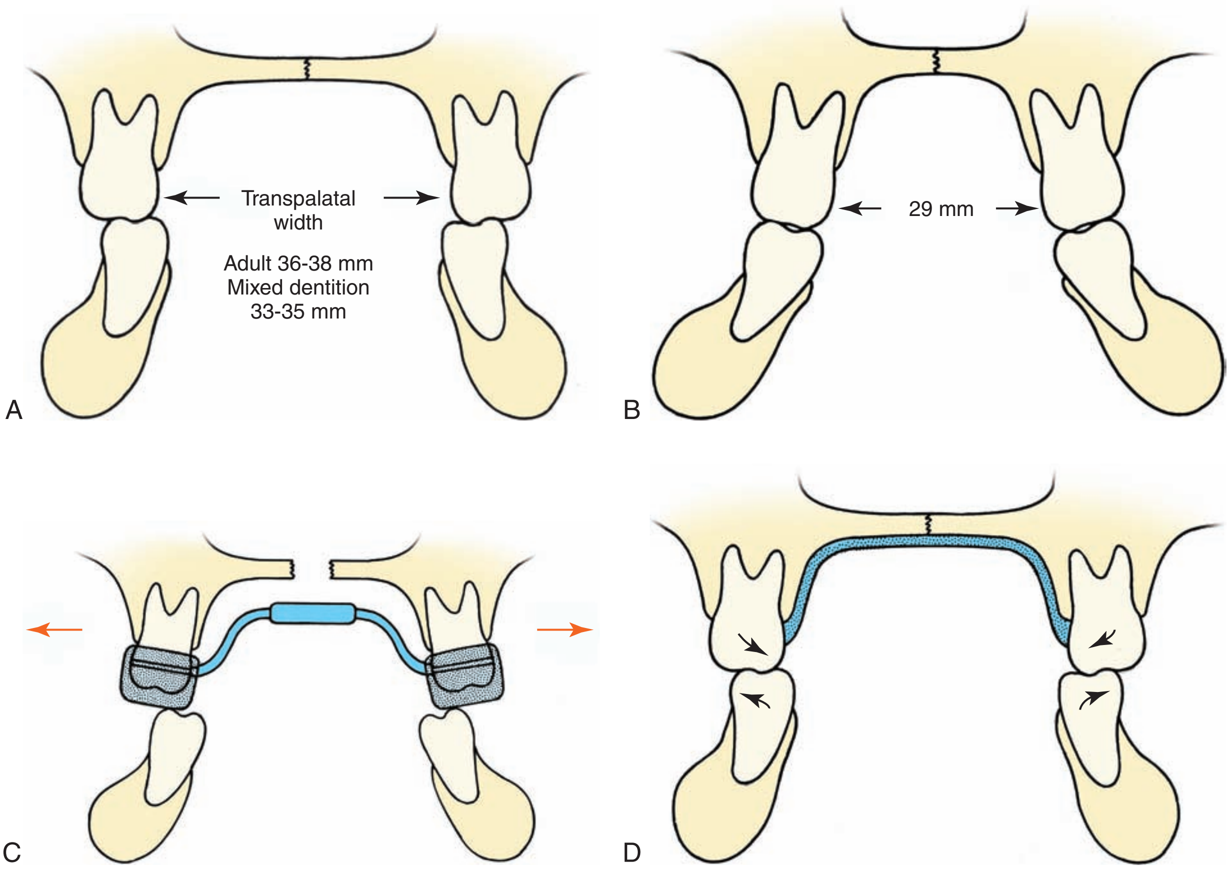

FIGURE 14-13 Frontal cross-sectional view of transpalatal dimensions through the molar region. **A,** Ideal transpalatal widths of the adult patient and the mixed dentition patient. **B,** Patient with a constricted maxilla, as indicated by the intermolar width of 29 mm. **C,** The effect of the bonded acrylic splint RME appliance. Note that the lingual cusps of the upper posterior teeth approximate the buccal cusps of the lower posterior teeth. **D,** The same patient during the post-RME period. A removable palatal plate has been added to stabilize the intra-arch relationship. Note the slight spontaneous uprighting of the dentition. *(Adapted from McNamara and Brudon.[1])*

After the active phase of expansion is completed, the appliance is left in place for an additional 5 months to allow for a reorganization of the midpalatal suture as well as other sutural systems affected by the expansion and to maximize the effect of the posterior bite block. At the end of the treatment time, the RME appliance is removed and the patient is given a removable palatal plate to sustain the achieved result (Figure 14-13, *D*).

The active expansion of the two halves of the maxilla produces a midline diastema between the two upper central incisors. During the period following the active expansion of the appliance, a mesial tipping of the maxillary central and lateral incisors usually is observed. Such spontaneous tooth movement is typical following RME, and this movement often is interpreted as being evidence of "relapse" by the patient or the parents. The clinician should advise the family about the probability of such spontaneous tooth migration. At 3 or 4 months following the initiation of RME treatment, brackets often are placed on the upper incisors to close the midline diastema and align the anterior teeth (Figure 14-14). In certain instances, a utility arch is used to retract, intrude, or protract the upper incisors, depending on the needs of the individual patient.

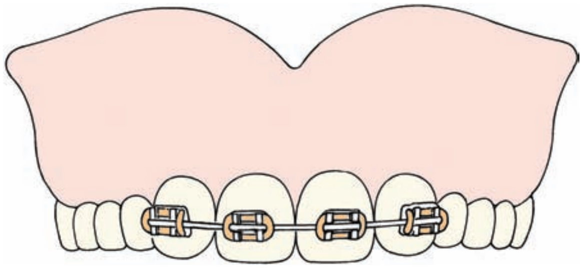

FIGURE 14-14 The placement of brackets on the upper anterior teeth to achieve incisal alignment.

Mandibular Adaptations. In patients whose lower arch exhibits moderate crowding of the anterior teeth or in whom the posterior teeth are tipped lingually, two types of appliances can be used prior to RME: the removable Schwarz appliance and the lip bumper. The use of these "decompensating" (i.e., expanding, uprighting) appliances began as a result of our initial experiences using the bonded RME appliances alone. We were able to produce the expected changes in maxillary transverse dimensions with the bonded expander readily, but we made no attempt to widen the lower dental arch actively. After evaluating RME in mixed dentition patients over a 5-year period, we discovered that in some patients, a spontaneous uprighting and "decrowding" of the lower teeth occurred, yet in others there was no change in the position and alignment of the lower teeth.

Because one of the cardinal rules of orthodontics was that one never should expand the lower arch, we were reluctant to do so. However, because expansion was observed in the lower arch on a sporadic basis using RME and because arch expansion was produced routinely by the FR-2 appliance of Fränkel,[78,91–93] we decided to attempt *orthodontic* expansion of the lower dental arch using either the removable Schwarz appliance or the lip bumper prior to *orthopedic* expansion of the maxilla. We assumed that expansion of the lower arch would not be stable unless the expansion was followed by maxillary orthopedic expansion.

Mandibular Dental Uprighting/Expansion Appliances

The Schwarz Appliance. The Schwarz appliance is a horseshoe-shaped removable appliance that fits along the lingual border of the mandibular dentition (Figure 14-15). The inferior border of the appliance extends below the gingival margin and contacts the lingual gingival tissue. A midline expansion screw is incorporated into the acrylic, and there are ball clasps that lie in the interproximal spaces between the deciduous and permanent molars.

The lower Schwarz appliance is indicated in patients with mild to moderate crowding in the lower anterior region or in instances in which there is significant lingual tipping of the posterior dentition. The appliance is activated once per week, producing 0.20 to 0.25 mm of expansion in the midline of the appliance. Usually the appliance is expanded for 4 to 5 months, depending on the degree of incisal crowding, producing about 4 to 5 mm of arch length anteriorly.

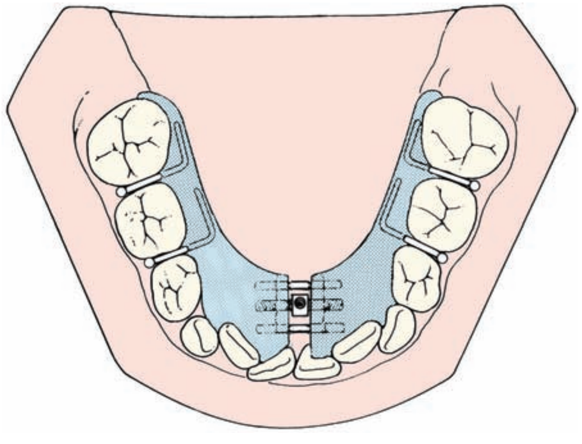

FIGURE 14-15 The removable lower Schwarz appliance that is used for mandibular dental decompensation. This appliance produces an orthodontic tipping (uprighting) of the lower posterior teeth and may create additional arch space anteriorly. *(Adapted from McNamara and Brudon.[1])*

Clinicians frequently have experienced difficulty understanding the reasoning underlying the use of the Schwarz appliance prior to RME. The following example illustrates the logic for this treatment decision. Figure 14-16, *A*, is a schematic drawing of a bilateral posterior crossbite, a condition that clinically is recognized easily and for which RME is a generally accepted treatment regimen. In this example, the mandibular bony base and dental arch are of normal width, and there is normal posterior dental angulation, whereas the maxilla is constricted.

The example shown in Figure 14-16, *B*, is from a patient who has maxillary constriction but in whom also there has been mandibular dentoalveolar "compensation" (i.e., the positions of the lower teeth have been influenced by the size and shape of the narrow maxilla). No obvious crossbite is present. Even though maxillary width is the same as in the previous example (Figure 14-16, *A*), the lower posterior teeth have erupted in a more lingual inclination. The palate appears narrow (in this example, a transpalatal width of 29 mm) and the arches are tapered in form. mild to moderate lower incisor crowding also is present (not shown). In such a patient, mandibular dental "decompensation" using a removable lower Schwarz appliance often is undertaken. The width and form of the mandibular dental arch is made more ideal prior to the time that RME is attempted. By decompensating the mandibular dental arch, greater arch expansion of the maxilla can be achieved than when RME is used alone.[94–96]

Simply stated, the purpose of the Schwarz appliance is to produce *orthodontic tipping* of the lower posterior teeth, uprighting these teeth into a more normal inclination (Figure 14-16, *C*). This movement is unstable if no further treatment is provided to the patient. A tendency toward a posterior crossbite is produced that is similar in many respects to the posterior crossbite shown in Figure 14-16, *A*.

Usually the Schwarz appliance is left in place until the maxillary orthopedic expansion phase is completed (Figure 14-16, *D*). As described earlier, the maxilla is expanded using a bonded acrylic splint appliance until the upper lingual cusps barely touch the lower buccal cusps. Following a 5-month period of RME stabilization, which allows adequate time for the midpalatal suture and the adjacent sutural systems to reorganize and reossify, both appliances are removed and the patient is given a simple maxillary maintenance plate (Figure 14-17), with no retention provided in the mandible. In instances of severe anterior malalignment in either arch, fixed

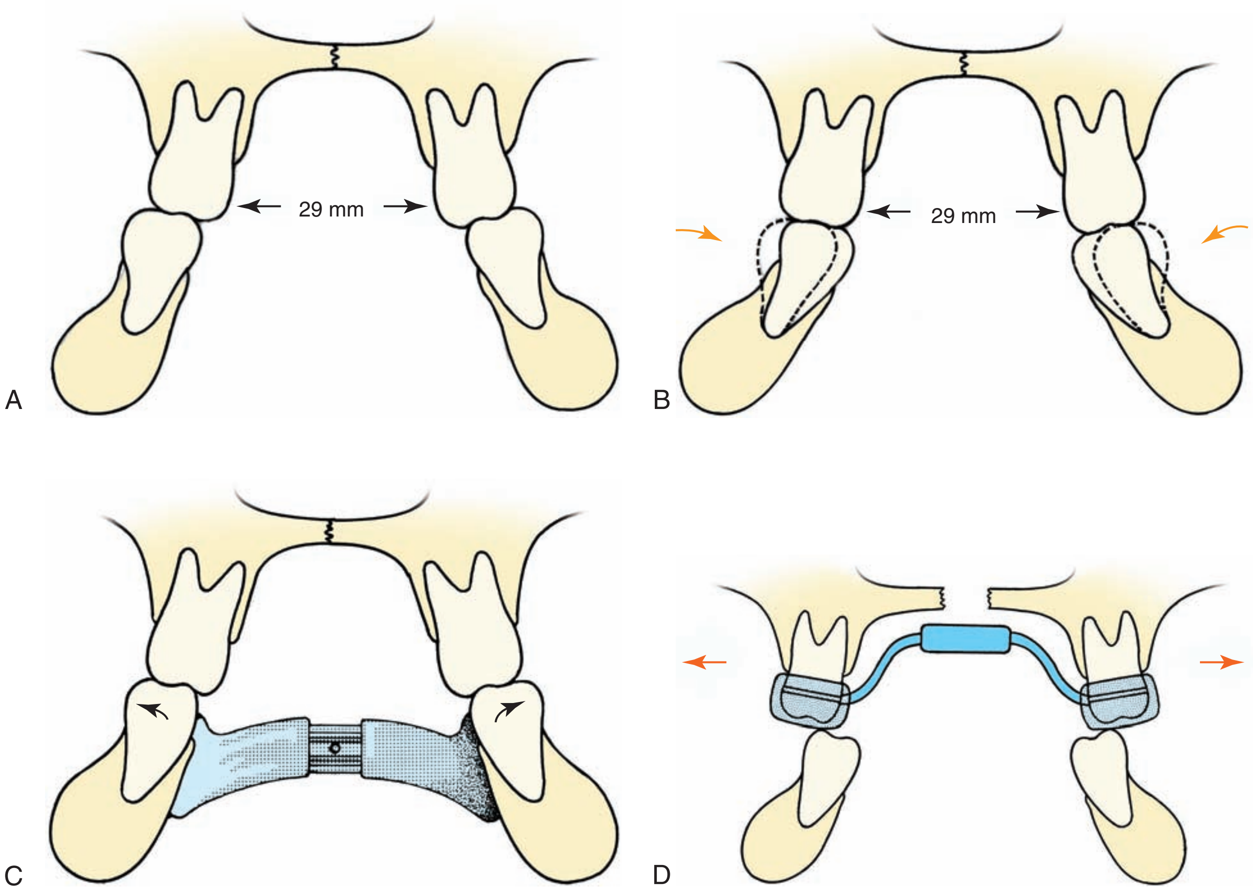

FIGURE 14-16 Frontal cross-sectional views. **A,** Patient with a constricted maxilla, properly uprighted lower posterior dentition, and a bilateral crossbite. **B,** Patient with a similar transpalatal width and with the body of the mandible in the same position as in **A**. Note the lower posterior teeth are more lingually inclined, camouflaging the maxillary constriction. The uprighting of the lower posterior teeth (i.e., mandibular dental "decompensation") is indicated prior to RME. **C,** The removable lower Schwarz expansion appliance uprights the lower molars, producing a tendency toward a posterior crossbite orthodontically. **D,** Rapid maxillary expansion following mandibular dental decompensation. The upper lingual cusps approximate the lower buccal cusps at the end of expansion. *(Adapted from McNamara and Brudon.[1])*

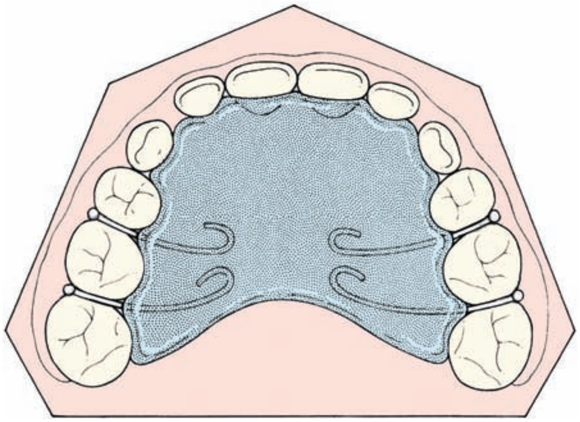

FIGURE 14-17 Simple maxillary stabilization plate. This appliance usually is worn on a near full-time basis for at least one year following RME removal. The acrylic of the plate also may serve as a guide plane for erupting canines and premolars. *(Adapted from McNamara and Brudon.[1])*

appliances may be placed on the incisors to align these teeth.

Lip Bumper. The lip bumper (Figure 14-18) is a removable appliance that also can be used for mandibular dental decompensation.[54,55,80,81] The lip bumper is particularly useful in patients who have very tight or tense buccal and labial musculature. The lip bumper lies away from the dentition and shields the dentition from the forces of the adjacent soft tissue. The appliance usually is worn on a full-time basis and may be ligated in place. The lip bumper also should lie at the gingival margin of the lower central incisors. The lip bumper not only increases arch length through passive lateral and anterior expansion but also serves to upright the lower molars distally, adding to the available arch length increase. Patients with lip bumper therapy must be monitored so as to avoid impacting the erupting second molars.

From a neuromuscular perspective, the lip bumper theoretically creates a more desirable treatment effect than does the Schwarz appliance (the Schwarz appliance simply produces orthodontic tipping of the teeth through direct force application to the dentition and alveolus). On the other hand, the lip bumper shields the soft tissue from the dentition, allowing for spontaneous arch expansion.[80,81] We tend to favor the use of the Schwarz appliance over the lip bumper, however, in most instances because of the predictability of the treatment outcome and the ease of clinical management. Only in patients with very constricted (tense) soft tissue is the lip bumper the appliance of choice.

SPONTANEOUS IMPROVEMENT OF SAGITTAL MALOCCLUSIONS

The major focus of this section of the chapter thus far has been the resolution of intra-arch tooth size–arch size discrepancy problems. Interestingly, there is another phenomenon that has been a serendipitous finding—“spontaneous” improvement of mild Class II and Class III malocclusions following RME.

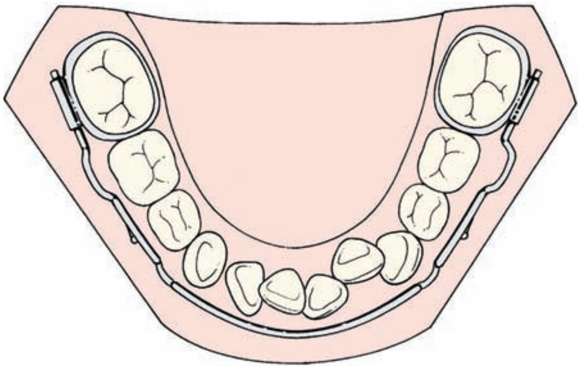

FIGURE 14-18 Occlusal view of a mandibular lip bumper that inserts into buccal tubes on the lower first permanent molar bands. *(Adapted from McNamara and Brudon.[1])*

Class II Patients

There are many patients in the mixed dentition who not only have intra-arch problems, but also have a Class II malocclusion or a strong tendency toward a Class II malocclusion. Generally, these patients do not have severe skeletal imbalances but rather may be characterized clinically as having either slight mandibular skeletal retrusion or an orthognathic facial profile with minimal neuromuscular imbalances.

According to the routine protocol described previously, these patients undergo RME with or without prior mandibular dental decompensation. At the time of expander removal, these patients will have a buccal crossbite tendency, with only the lingual cusps of the upper posterior teeth contacting the buccal cusps of the lower posterior teeth (Figure 14-19, *A*). A maxillary maintenance plate typically is used to stabilize this relationship. Several appointments later, some interesting observations are noted: the tendency toward a buccal crossbite has disappeared (Figure 14-19, *B*), and the patient now has a solid Class I sagittal occlusal relationship.

Clinicians traditionally have viewed a Class II malocclusion as primarily a sagittal and vertical problem. Our experience with the post-RME correction of the Class II problem indicates that many Class II malocclusions also have a strong transverse component. The overexpansion of the maxilla, which subsequently is stabilized through the use of a removable palatal plate, disrupts the occlusion. It appears that the patient becomes more

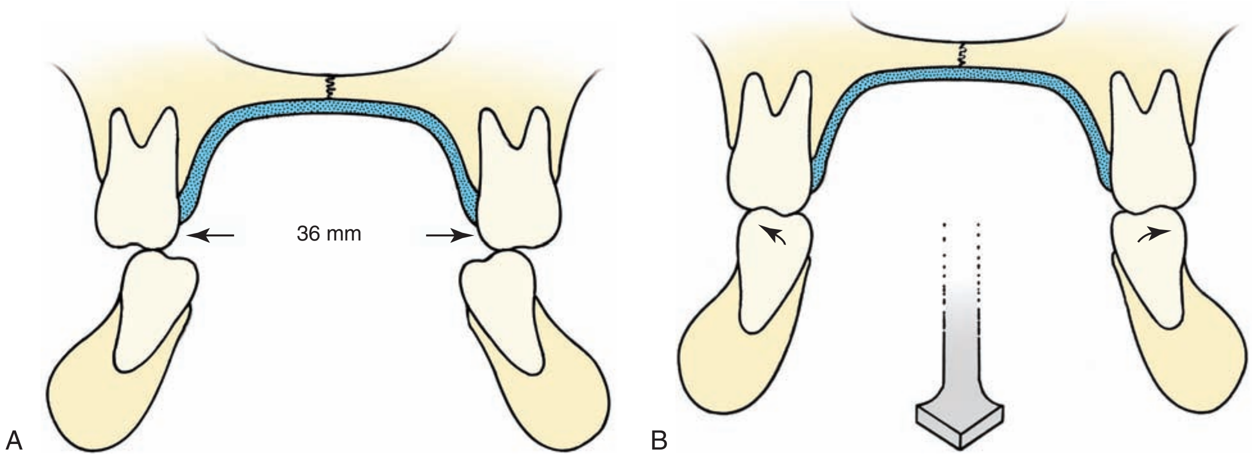

FIGURE 14-19 Frontal cross-sectional view of patient during the post-RME period. **A,** The maxilla has been expanded so that the intermaxillary width is 36 mm, as measured between the upper first permanent molars. Note the tendency toward a buccal crossbite bilaterally. **B,** During the postexpansion period, note that the lower dentition has uprighted slightly, and there has been a forward sagittal movement of the mandible as the patient seeks to find a more stable position in which to occlude. *(Adapted from McNamara and Brudon.[1])*

comfortable by positioning his or her lower jaw slightly forward, thus eliminating the tendency toward a buccal crossbite and at the same time improving the overall sagittal occlusal relationship. In many respects, the teeth themselves act as an endogenous functional appliance, encouraging a change in mandibular posture and, ultimately, a change in the maxillomandibular occlusal relationship.

The correction of a Class II tendency patient is illustrated in Figure 14-20. Figure 14-20, *A*, shows the sagittal view of the skeletal and dentoalveolar structures of a Class II tendency patient who has excessive overjet and a narrow maxilla. The placement of a bonded maxillary expansion appliance immediately causes an increase in the vertical dimension of the face, because of the posterior occlusal coverage. This change is beneficial in most patients, in that the temporary increase in the vertical dimension prevents extrusion of the posterior teeth during the expansion process.[88] This treatment also may result in an upward slightly forward displacement (Figure 14-20, *B*) of the maxilla (this phenomenon will be discussed subsequently in the discussion of the spontaneous improvement of Class III). During the post-RME period, during which a removable palatal plate is worn (Figure 14-20, *C*), the mandible is postured forward by the patient because of the overexpansion of the maxilla. Thus, the spontaneous improvement of patients with a tendency toward a Class II malocclusion does not occur during the active expansion period but rather during the time that the maintenance plate is being worn.

Because of the perceived importance of this issue, we have conducted two prospective clinical trials investigating this phenomenon. Guest and co-workers[97] contrasted the treatment results of 50 Class II or end-to-end patients treated with a bonded expander to 50 matched untreated controls (Figure 14-21). The analysis of serial cephalometric films taken 4 years apart indicated that the bonded RME had its greatest effects at the occlusal level, specifically producing highly significant improvement of Class II molar relationship and a decrease in overjet. The Class II molar relationship remained virtually unchanged in the control group, while the RME group showed an improved molar relationship of more than 1 mm in more than 90% of the expansion patients, and more than 2 mm in almost 50% (see Figure 14-21). The second study[98] on a larger group of patients (500 RME, 188 controls) from our private practice revealed similar results.

Thus, this improvement in Class II relations occurs with such frequency that it can be included as part of the overall treatment plan. If the resulting occlusion remains Class II at the time of Phase II treatment, then definitive Class II corrective procedures (e.g., Herbst appliance, Pendex appliance) can be initiated.

Class III Patients

The use of a bonded RME appliance also can lead to a spontaneous occlusal improvement in a patient with a tendency toward a Class III malocclusion. At first glance, this phenomenon seems paradoxical, given the previous discussion concerning the spontaneous improvement of Class II tendency problems. The mechanism of Class III correction, however, is distinctly different than that described previously.

An examination of Figure 14-20, *B*, provides some explanation for this phenomenon. The placement of an acrylic splint expander that opens the bite vertically 3 mm not only provides an intrusive force against the maxilla,[88] presumably due to the stretch of the masticatory musculature, but also may produce a slight forward

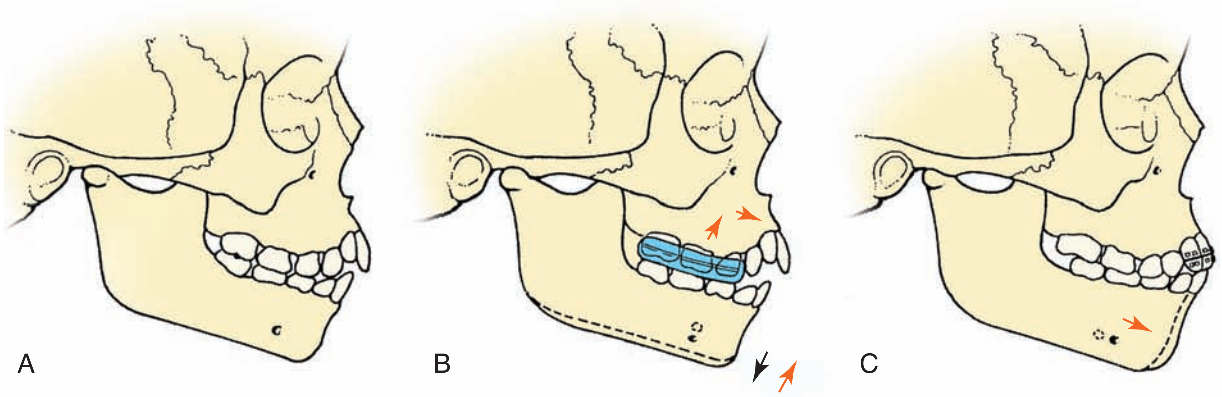

FIGURE 14-20 Sequence of events leading to a spontaneous improvement in the sagittal malocclusion. **A,** Pretreatment. The patient has excessive overjet and an end-to-end molar relationship. **B,** The placement of the appliance immediately creates a downward rotation of the position of the mandible due to the posterior occlusal acrylic. During treatment, an intrusive (and slightly protrusive) force is produced on the skeletal and dental structures of the maxilla. **C,** During the postexpansion period, the upper dental arch has been widened. The lower jaw often is postured forward to achieve a more stable occlusal relationship. In this illustration, brackets have been placed on the upper anterior teeth to facilitate incisal alignment.

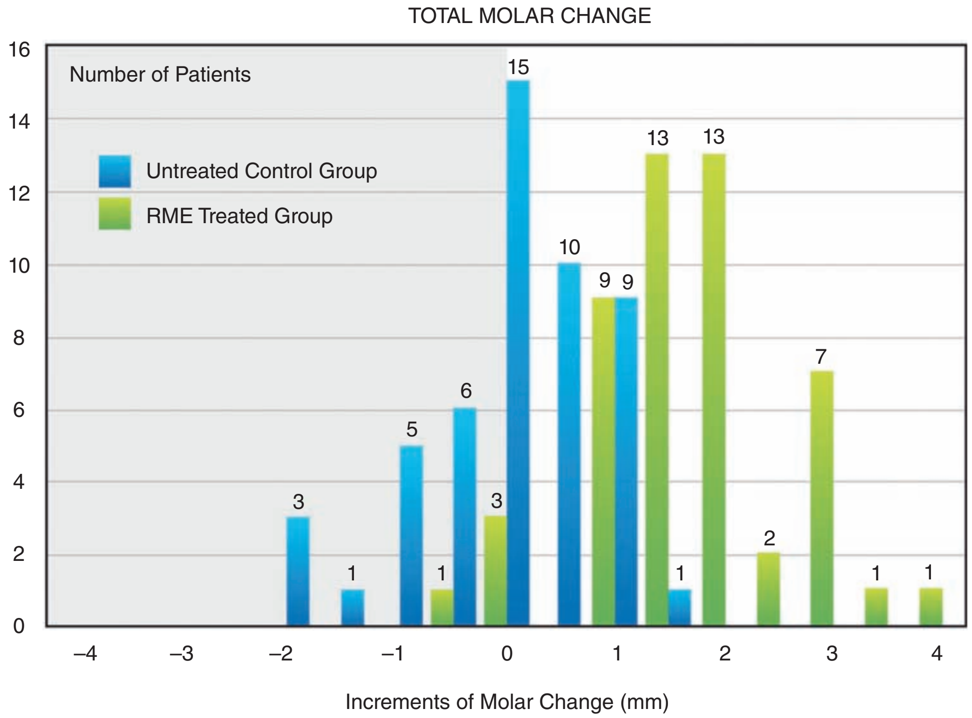

FIGURE 14-21 Prospective clinical study of spontaneous improvement in Class II molar relationship following expansion in the early mixed dentition. Both the treated and control groups had 50 patients or subjects. The interval between the two lateral cephalometric films analyzed was 4 years. There was virtually no change in the control subjects, whereas 92% improved toward Class I in the treated group, nearly 50% by 2 mm or more. *(From Guest et al.[97])*

repositioning of the maxilla. A slight forward movement of the maxilla following RME has been documented in both clinical[45] and experimental[99] studies. In addition, the placement of a bonded expander with acrylic coverage of the occlusion helps eliminate a tendency toward a pseudo–Class III malocclusion.

As with the Class II tendency patients described previously, patients in whom a borderline Class III malocclusion exists usually have a reasonably balanced facial pattern, often with only a slight tendency toward maxillary skeletal retrusion. Obviously, in patients in whom Class III malocclusion persists after expansion, more aggressive types of therapy are indicated, as will be discussed later.

When contrasting the spontaneous improvement of both Class II and Class III tendency patients, it must be emphasized that any spontaneous improvement of a Class III malocclusion usually occurs (if it does occur) during the *active* phase of treatment (within the first 30 or 40 days). The spontaneous correction of Class II malocclusion usually is noted during the *retention* phase, after the bonded expander has removed and the maintenance plate has been worn for 6 to 12 months. When planning the treatment for a Class III tendency patient, facial mask hooks may be attached to the expansion appliance to facilitate the use of a facial mask if that treatment is deemed necessary at a later time.

THE TREATMENT OF CLASS II MALOCCLUSION

A number of treatments are available for correcting Class II malocclusions, including a variety of extraoral traction appliances, arch expansion appliances, extraction procedures and functional jaw orthopedic appliances. Each treatment approach, however, differs in its effect on the skeletal structures of the craniofacial region, sometimes accelerating or limiting the growth of the various craniofacial structures involved.

Components of Class II Malocclusion

Numerous studies have considered the components of Class II malocclusions, with most focusing on patients in the adolescent or adult age range.[100–104] These studies have shown that the term "Class II malocclusion" is not a single diagnostic entity but rather can result from numerous combinations of skeletal and dentoalveolar components.

McNamara[105] has shown that in mixed dentition Class II subjects prior to treatment, mandibular skeletal retrusion was the most common single characteristic of his Class II sample (N = 277). Substantial variation also was noted in the vertical development of the face, with one-third to one-half of the sample having increased vertical facial dimensions. The anteroposterior position of the maxilla on average was neutral, with far more instances of maxillary skeletal retrusion than maxillary skeletal protrusion being observed. When measures independent of mandibular position were used for evaluation, the upper incisors of the Class II sample were on average in a normal anteroposterior position, with more instances of maxillary dentoalveolar retrusion than maxillary dentoalveolar protrusion being observed.[105] The lower incisors usually were well positioned anteroposteriorly, but instances of mandibular dental retrusion and protrusion also were noted.

Available Class II Treatment Strategies

Once the skeletal and dentoalveolar components of an individual Class II malocclusion are identified, using data gathered from the clinical examination and a cephalometric analysis as well as from study models, the appropriate treatment regimen is selected. This discussion will focus on the treatment of problems of Class II malocclusion that are primarily skeletally related, with specific emphasis on *maxillary distalization* and *mandibular enhancement* mechanics, two of the most commonly used treatment approaches.

Maxillary Distalization. In patients in whom there is a forward positioning of the maxillary dentition relative to the bony base of the maxilla, either extraction protocols (i.e., ultimately removing the upper first premolars) or dentoalveolar distalizing mechanics (e.g., Pendulum/Pendex appliance,[106–108] Distal Jet,[109–112] distalizing magnets,[113] NiTi coils,[114] removable plates with finger springs[54]) also can be used.

Extraoral Traction. The most common treatment for true maxillary skeletal protrusion is extraoral traction. Extraoral traction appliances can be divided arbitrarily into two types: facebows and headgears. Facebows attach to tubes on the maxillary first molar bands, whereas a headgear attaches directly to the archwire or to auxiliaries connected to the archwire.

The cervical (low-pull) *facebow* (Figure 14-22, *A*) is used most frequently in patients with decreased vertical facial dimensions. The inner bow of the facebow is anchored to tubes that are placed on the buccal surface of bands that are attached to the upper first molars. The outer bow is connected to strap that extends to the cervical region and is anchored against the dorsal aspect of the neck. Usually the outer bow of the facebow lies above the plane of occlusion (e.g., 15 to 20 degrees) so that the force is directed through the center of resistance in order to prevent distal tipping of the molars during treatment. Numerous clinical studies[28–32,115] have shown that the forward movement of the maxilla can be inhibited through the use of this type of appliance. Cervical traction also can increase the vertical dimension through the extrusion of posterior teeth.

The direction of extraoral force can be altered, depending on the placement of the attached anchoring units. For example, a high-pull facebow (Figure 14-22, *B*) is used in individuals in whom increases in vertical dimension are to be minimized or avoided. The facebow is anchored to an occipital anchoring unit (headcap) to produce a more vertically directed force. As a growth guidance appliance, a high-pull facebow can decrease the vertical development of the maxilla, thereby allowing for autorotation of the mandible and maximizing the horizontal expression of mandibular growth.[35] A facebow also can be anchored simultaneously to a cervical neck-strap and a headcap, a combination often termed a *straight-pull* or *combination facebow*.

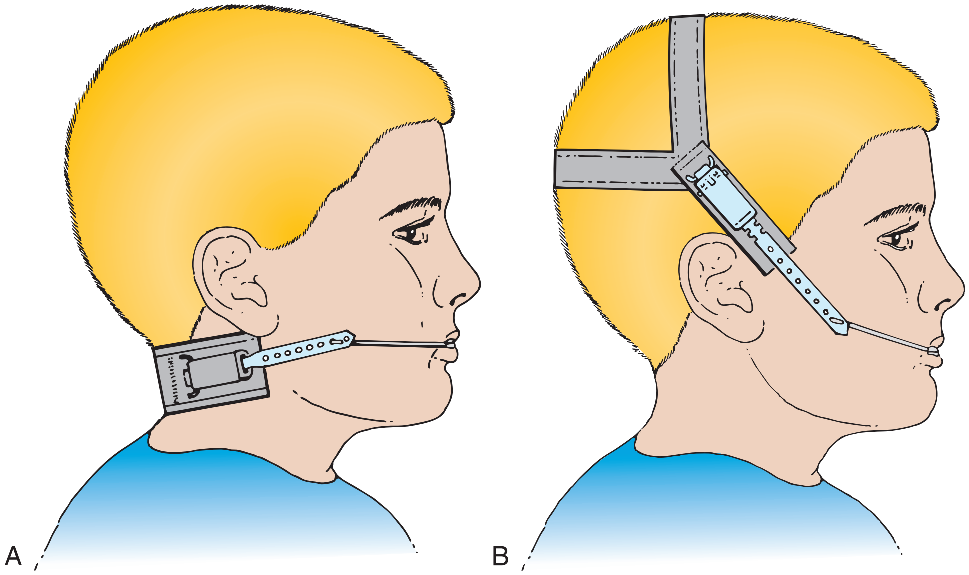

FIGURE 14-22 Extraoral traction. **A,** Low-pull (cervical) face bow with safety connector. **B,** High-pull facebow with safety connector. *(Adapted from McNamara and Brudon.[1])*

The forces produced by extraoral traction also can be attached anteriorly to the archwire through the use of a J hook *headgear*. Flared upper incisors can be retracted using either a straight-pull (Figure 14-23, *A*) or a high-pull headgear (Figure 14-23, *B*) combined with J hooks that are attached to the archwire anteriorly or by using a closing arch supported by headgear. A headgear with J hooks also is used to potentiate archwire mechanics by helping control forces incorporated into the archwire (e.g., torque, intrusion).

The use of the Interlandi-type headgear (Figure 14-24) provides an additional treatment option with a variable direction of force. J hooks can be applied to the maxillary teeth in a variety of force vectors to retract and intrude the upper incisors (Figure 14-24, *A*). A similar type of retraction-stabilization of the mandibular dental arch also can be achieved. In addition, it is possible to attach to a high-pull headgear to the upper arch and a straight-pull headgear to the lower arch simultaneously (Figure 14-24, *B*).

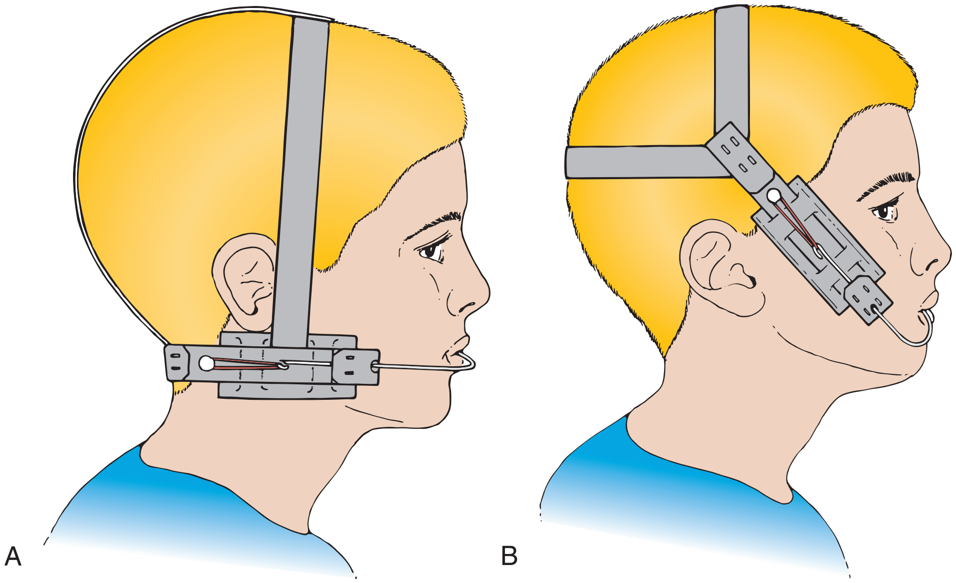

FIGURE 14-23 Headgear. **A,** Straight-pull headgear with J hooks. **B,** High-pull headgear with J hooks. *(Adapted from McNamara and Brudon.[1])*

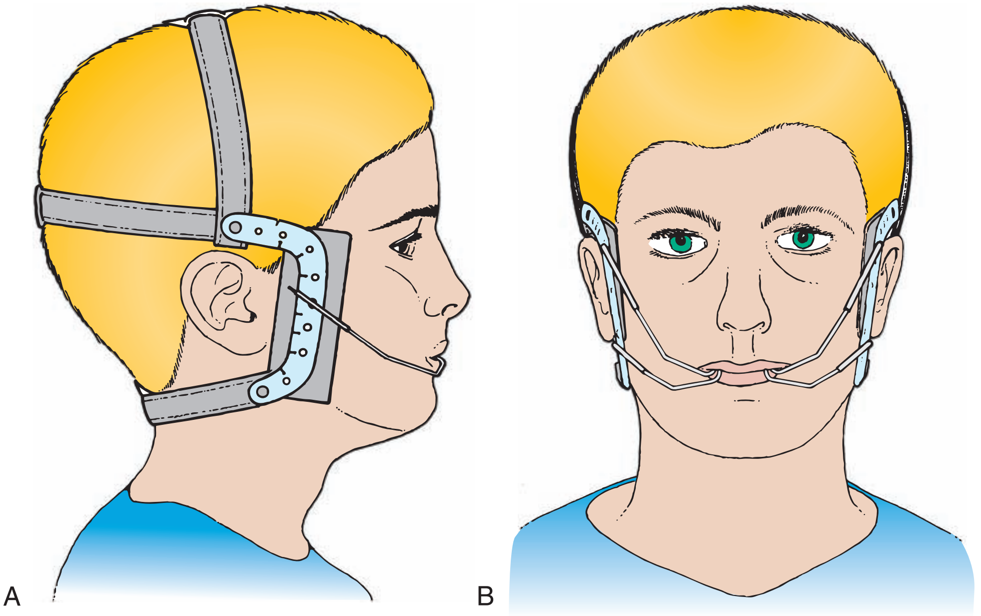

FIGURE 14-24 Interlandi-type headgear. **A,** Single pull to the maxillary dentition. **B,** Attachment of the J hooks to both the maxillary and mandibular dental arches. *(Adapted from McNamara and Brudon.[1])*

Virtually all of the extraoral traction appliances described earlier restrict the normal downward and forward movement of the maxilla and also may help retract the maxillary and mandibular dentitions. These types of appliances are indicated in instances of maxillary skeletal protrusion, maxillary dentolaveolar protrusion, and mandibular dentoalveolar protrusion. The direction of force (i.e., low-pull, straight-pull, high-pull) is determined in part by the pretreatment vertical dimensions of the patient and treatment goals.

Maxillary Molar Distalization. The use of "distalization" mechanics to correct Class II malocclusions is a common treatment modality. A survey by Sinclair[116] found that all responding orthodontists reported with molar distalization. However, nearly all indicated that patient cooperation was the most significant problem encountered in distalizing maxillary molars. Most traditional approaches to molar distalization, including extraoral traction, Wilson distalizing arches, removable spring appliances, and intermaxillary elastics with sliding jigs require considerable patient compliance to be successful. More recently, problems of predicting patient behavior have led many clinicians to devise appliances that minimize reliance on the patient and which are under the control of the clinician. Relying on the patient's willingness to wear an appliance consistently may result in increased treatment time, a change of treatment plans, or both.

Pendulum and Pendex Appliances. A popular method of molar distalization that requires no patient cooperation is the "Pendulum" appliance system. In 1992, Hilgers described the development of two hybrid appliances, the Pendulum and Pendex. Modifications in appliance design and clinical management also have been described by Hilgers and Bennett.[117,118]

The *Pendulum appliance* (Figure 14-25) consists of a large acrylic Nance button that covers the midportion of the palate. The acrylic pad is connected to the dentition by means of occlusal rests that extend from the lateral aspect of the pad and are bonded to the occlusal surfaces of the upper first and second premolars. Posteriorly directed springs, made of 0.032-inch TMA™ wire, extend from the distal aspect of the palatal acrylic to form a helical loop near the midline and then extend laterally to insert into lingual sheaths on bands cemented on the upper first molars.

When in a passive state, the springs extend posteriorly, approaching the midpalatal raphe. When activated and inserted into the lingual sheaths, they produce a distalizing force against the upper first molars that moves the molars distally and medially (Figure 14-26). Hilgers[106] estimates that these springs deliver approximately 230 grams per side to the maxillary molars. The springs also may have adjustment loops that can be manipulated to increase molar expansion, molar rotation, or distal root tip.[119]

The design of the *Pendex appliance* (Figure 14-27) is essentially the same as the Pendulum, except for the addition of a palatal expansion screw in the midline (hence the name "Pendex"). In most instances, we use the Pendex design because of the tendency toward transverse maxillary constriction in patients with Class II malocclusion as well as the trend toward lingualization of molars as they are distalized with this type of appliance.

The so-called "T-Rex" configuration of the Pendex is our design of choice. This design features two wires that extend from the palatal acrylic and are soldered to the lingual aspect of the upper first molars. These wires provide addition stability to the Pendex appliance during the expansion phase of treatment (Figure 14-28). They are removed when the molar distalization phase is initiated after adequate expansion has been achieved (Figure 14-29). After molar distalization is complete, the

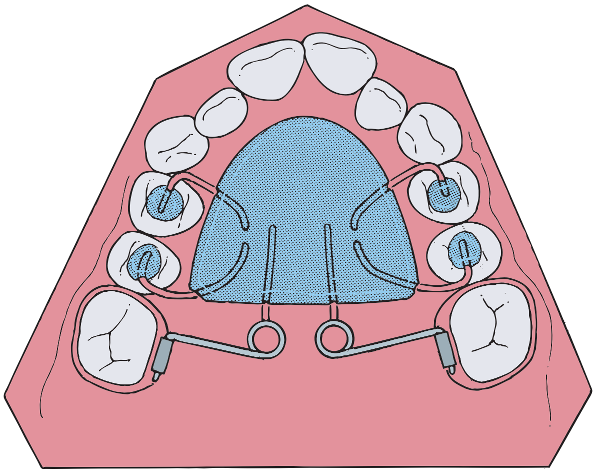

FIGURE 14-25 The Pendulum appliance of Hilgers that has been bonded in place after cementing the molar bands. The distalizing springs are activated after the occlusal rests have been bonded to the premolars by placing the ends of the springs into the lingual sheaths on the upper first molars.

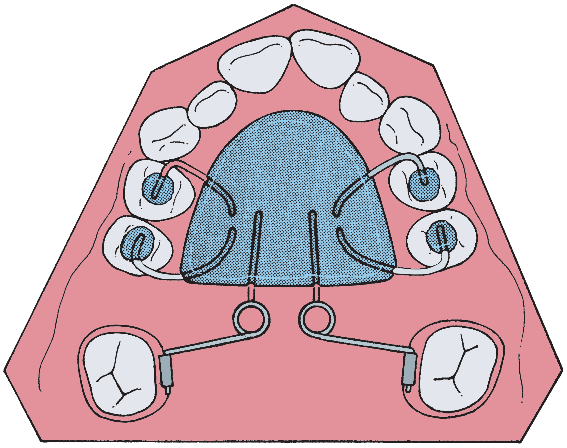

FIGURE 14-26 The Pendulum appliance after distalization of the upper first molars. Note the tendency to move these teeth medially as they are being distalized.

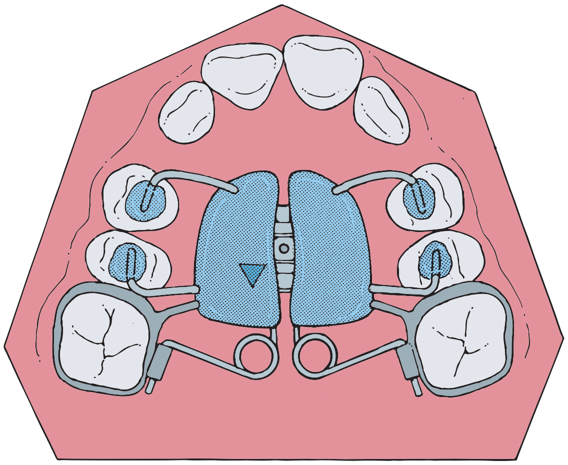

FIGURE 14-27 The "T-Rex" design of the Pendex appliance of Hilgers. Locking wires connect the bands on the upper first molars to the acrylic button. These connecting wires are removed after the desired expansion has been achieved, partially counteracting the medial action of the distalizing molar springs.

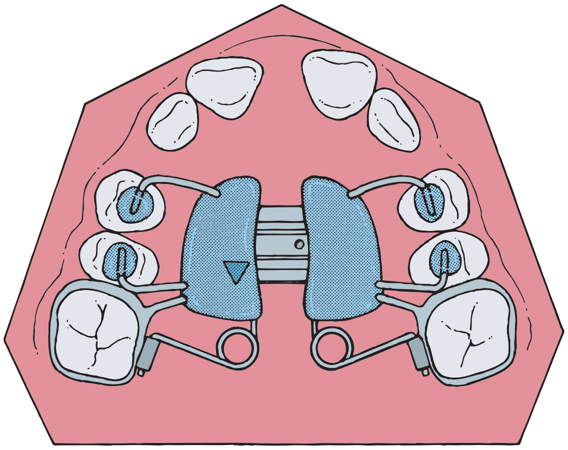

FIGURE 14-28 The Pendex appliance after expansion. The locking wires still connect the molar bands to the acrylic Nance button.

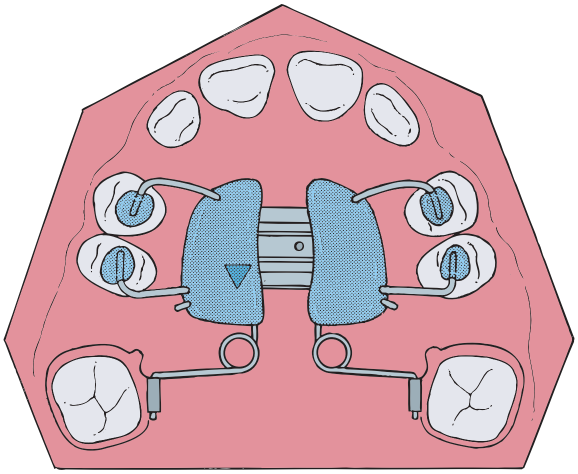

FIGURE 14-29 Full activation of the Pendex appliance. The upper first molars now are in an overcorrected ("super Class I") relationship with the lower first molars.

occlusal rests can be removed from the maxillary second premolars allowing for distal migration as a result of the pull of the transseptal fibers (Figure 14-30).

Following appliance removal, a Nance holding arch with a palatal button (Figure 14-31) is delivered to the patient within the next 24 hours. The Nance holding arch is left in place until proper distilization of the premolars and canines is achieved. Final distalization of the premolars and canines is accomplished by placing brackets on these teeth and using elastomeric chain sequentially to move these teeth distally one at a time per side (i.e., moving "beads on a string"). Anterior space closure can be achieved by way of a retraction utility arch or an anterior closing loop arch. Typically, space closure also is supported by Class II elastics. For further details concerning the clinical management of the appliance, the reader is referred to the McNamara and Brudon text.[1]

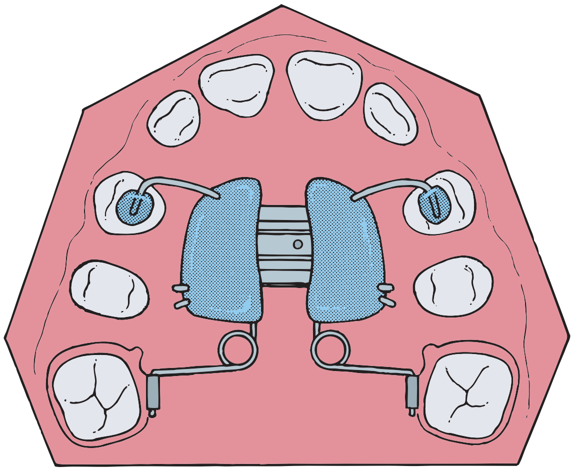

FIGURE 14-30 The spontaneous movement of the upper second premolars distally due to the pull of the transseptal fibers after the occlusal rests on the maxillary second premolars were removed.

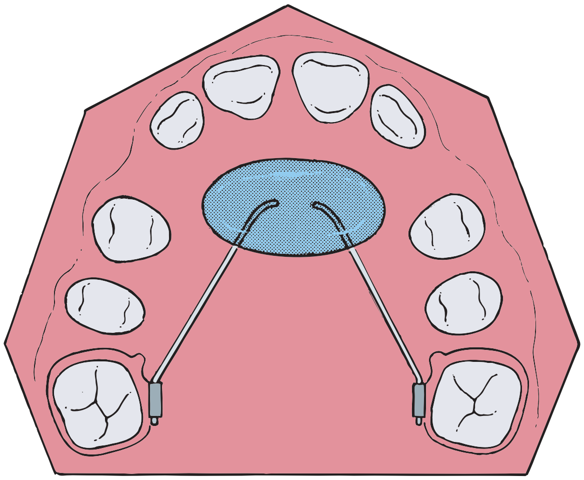

FIGURE 14-31 Placement of a Nance holding arch following molar distalization.

Mandibular Enhancement: Functional Jaw Orthopedics

The previous section described several approaches aimed at correcting a Class II molar relationship by moving the maxilla and/or the maxillary posterior teeth distally. A second type of treatment modality aimed at correcting a Class II malocclusion focuses its mechanics on influencing the mandibular dentition and the growth of the mandible. This type of treatment is referred to as *functional jaw orthopedics* (FJO), with the intent of treating occlusal problems associated, at least in part, with mandibular skeletal retrusion.

The concept of functional jaw orthopedics or advancement of the mandible is not new to dentistry. In 1880, Kingsley[120] wrote of "jumping the bite" and forward posturing the mandible. Yet given its long history, such appliances were used rarely in the United States until the mid 1970s. Over the past 30 years, there has been a gradual evolution regarding the way in which functional jaw orthopedics is used in a contemporary orthodontic practice, especially concerning appliance selection, the timing of intervention, and the need for "pre-orthopedic" orthodontic treatment.

Like in most aspects of orthodontics, there are many ways to achieve a similar outcome. This is true of FJO appliances, with their differences in both material and design. The orthodontic literature describes a variety of appliance designs, including the activator,[121] the bionator,[5,122,123] the Fränkel appliance,[2,78,124,125] the Bimler appliance,[126,127] the Herbst appliance,[108,128–130] the mandibular anterior repositioning appliance (MARA) appliance,[131] and the twin block appliance.[132–135] Although these appliances may appear very different at first glance, they all work to achieve a Class I occlusion by posturing the mandible forward during a time of growth.

It is not the purpose of this chapter section to debate whether functional jaw orthopedic appliances do or do not enhance mandibular growth, a topic of great controversy during the past 25 years. The question of whether the mandible can be increased in length in comparison with untreated controls has been addressed in numerous experimental studies.[22,136–148] In addition, a number of clinical studies of various appliances have been conducted.[23,78,129,130,149–154] As mentioned earlier, the bulk of scientific evidence indicates that, in growing individuals, mandibular growth can be enhanced over the short term. One of the more rigorous studies of FJO that analyzed patients treated by Rolf Fränkel[2] showed that the residual increase in mandibular length was on average 3 mm, not 5 to 8 mm (an amount that would be equivalent to a surgical mandibular advancement). The long-term effect on mandibular length still remains open to question.

The major question remaining is whether or not the extra growth has clinical relevance. It is our belief that the skeletal adaptations, combined with dentoalveolar changes, can lead to a significant correction of a Class II malocclusion using a variety of FJO treatment modalities. Whereas these questions regarding the existence of extra growth as a result of functional jaw orthopedics can be studied and debated further, the clinical effectiveness of the use of these appliances is less debatable. Experience has shown us that by posturing the lower jaw forward into a Class I or an end-on Class III relationship during a time of maximum mandibular growth, the lower jaw grows forward into its "postured position" without "dragging" the upper teeth with it. With proper appliance selection, treatment timing, and patient compliance, one may achieve a major orthodontic goal of obtaining a Class I molar and canine relationship.

Appliance Selection. All functional jaw orthopedic appliances have one aspect in common: they induce a forward mandibular posturing as part of the overall treatment effect. Presumably, this alteration in the postural activity of the muscles of the craniofacial complex ultimately leads to changes in both skeletal and dental relationships.[78]

Herbst Appliance. An appliance that has proved satisfactory in the treatment of Class II malocclusions in the permanent dentition is the Herbst appliance, a fixed or removable functional appliance depending on the anchoring system used. The original bite-jumping mechanism was developed by Herbst,[128] and the banded design of the appliance was reintroduced in the late 1970s by Pancherz[129,149–151] and refined later by Rogers.[155,156] Designs that incorporate stainless steel crowns as anchoring mechanisms have been advocated by Goodman and McKenna,[157] Dischinger,[158] Smith,[159] and Mayes.[160,161]

We have used many types of fixed Herbst appliances over the years, with the current preferred version incorporating stainless steel crowns on the maxillary first molars and mandibular first premolars (Figure 14-32). (Figure 14-32 shows only the upper aspect of the appliance.) Our routine prescription also includes an RME screw with lingual wires extending anteriorly to the premolars. A removable acrylic splint design Herbst appliance[162–164] also has been used successfully in our practice for several decades (Figure 14-33). The banded Herbst as described by Rogers (Figure 14-34) has a number of features that prove helpful. In particular, there is no interference with the occlusion, it is easier to precisely fit, and removal of the appliance is easier.

Clinical studies of the fixed and removable designs of the appliance indicate that both skeletal and dentoalveolar adaptations are produced.[108,130,150] Generally speaking, about 50% of the treatment effect is due to tooth movement, primarily the backward and upward movement of the posterior dentition. The primarily skeletal treatment effect produced is a short-term increase in mandibular growth (i.e., 2.0 to 2.5 mm greater than normal values).[108,130,150,165]

There is no question that a Class I molar relationship can be achieved in most growing Class II patients

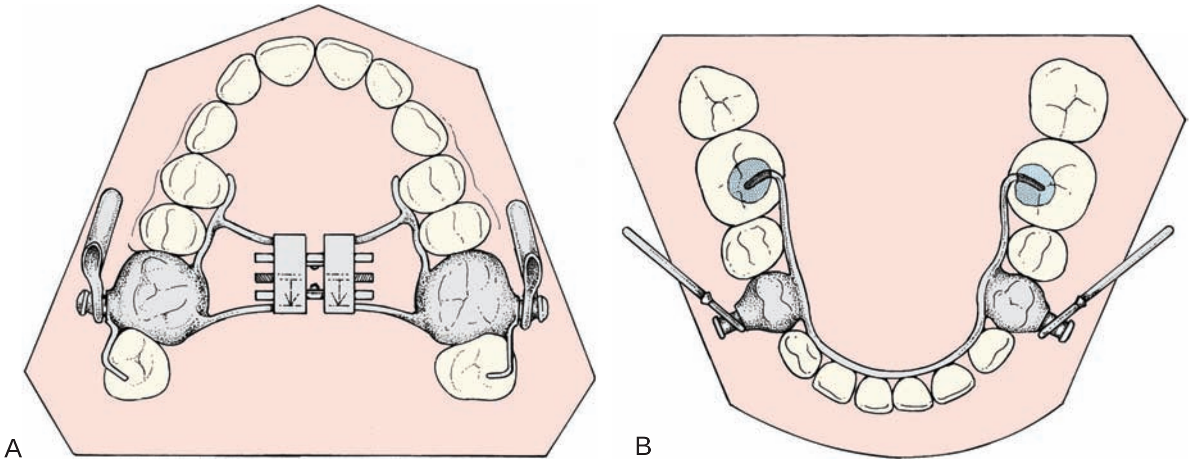

FIGURE 14-32 The stainless steel crown Herbst® appliance. **A,** Maxillary portion. Stainless steel crowns are placed on the upper first molars and a rapid maxillary expansion screw typically is placed in the midpalatal region. **B,** Mandibular portion. Stainless steel crowns are placed on the lower first premolars. A lower lingual wire made from 0.036-inch stainless steel extends from first molar to first molar. Occlusal rests are bonded to the lower first molars bilaterally.

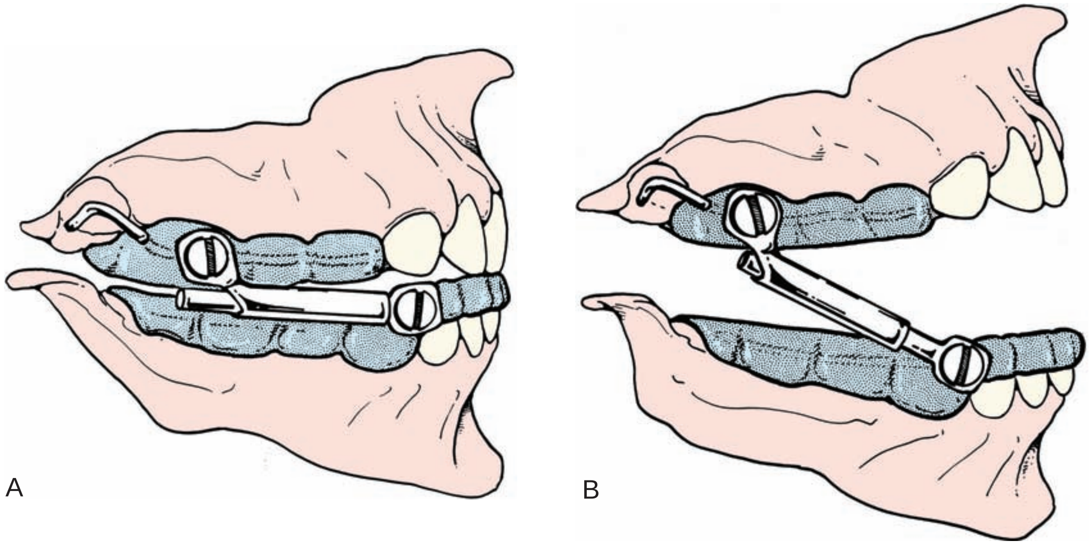

FIGURE 14-33 **A,** The acrylic splint Herbst® appliance made from 3-mm-thick splint Biocryl. **B,** The Herbst® bite jumping mechanism.

following Herbst appliance treatment. It has been our experience, however, that a Herbst appliance is not the appliance of choice in mixed dentition patients. After having followed patients originally treated in the mixed dentition for several years after Herbst therapy was completed but before the placement of fixed appliances was initiated, we have noted a significant tendency toward a relapse to the original malocclusion. This finding also has been noted by others.[166,167] This observation concerning Herbst patients treated in the mixed dentition may be due, in part, to the lack of direct effect on the orofacial musculature produced by the Herbst appliance (in contrast to the FR-2 appliance) and also may be related to the shape of the deciduous teeth. The posterior deciduous teeth tend to be relatively flat and thus do not provide the same type of occlusal interdigitation as occurs in the permanent dentition.

Our lack of success using the Herbst appliance in the mixed dentition does not eliminate this appliance from consideration. As mentioned earlier, we will initiate regimens in the early mixed dentition to address intra-arch space discrepancy problems and will postpone functional appliance treatment until after all deciduous teeth are lost and the succeeding teeth are erupted. This delayed intervention is particularly useful in patients who have excessive vertical facial development and steep mandibular plane angles. We have found that by intervening in the early permanent dentition using the Herbst appliance, satisfactory skeletal and dental adaptations have been noted overall. This appliance is used most

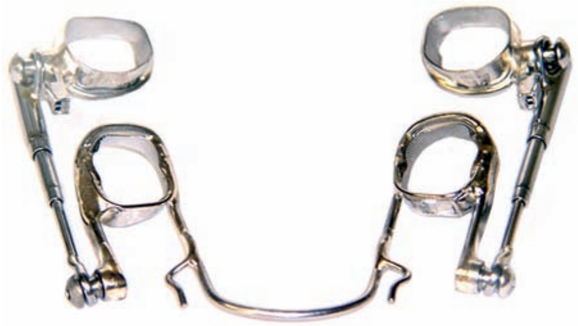

FIGURE 14-34 The banded Herbst® provides ease and accuracy of fit, minimal increase in bite opening, and ease of removal. The advancing arm is telescoping (providing for a smaller appliance profile) and the anterior attachments of the lower member allow for increased lateral range of mandibular function. The lingual wire is 0.051 inch, and rests are placed either on the first or second premolar. The "bands" are either occlusal-removed crowns or heavier material bands with reinforcing wires on the occlusal. Archwire tubes are incorporated to control intra-arch mechanics.

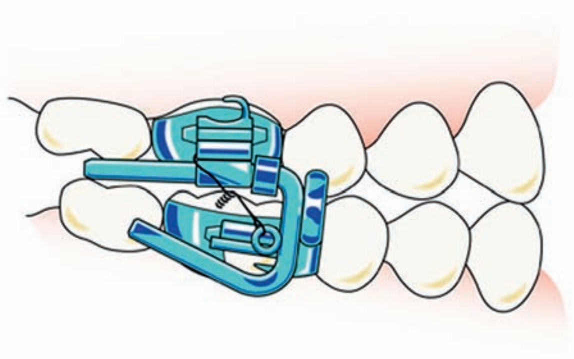

FIGURE 14-35 Mandibular anterior repositioning appliance (MARA). The arm soldered to the lower stainless steel crown forces the lower jaw anteriorly during closure.

effectively in patients who do not have profound neuromuscular imbalances.

MARA Appliance. Another appliance gaining popularity for correction of Class II malocclusions is the mandibular anterior repositioning appliance or MARA appliance.[131,168,169] The MARA is a fixed tooth-borne appliance that is fabricated on stainless steel crowns commonly placed over the maxillary and mandibular first permanent molars (Figure 14-35). It has been used throughout the mixed and early permanent dentition stages, with similar indications as the Herbst appliance described earlier. The MARA acts by prohibiting the patient from closing in a natural, Class II relationship. Upon mandibular closure, the MARA's extension arms interfere, making it so that the mandible must be postured forward in order for intercuspation to occur.[168]

The MARA appliance produces treatment effects that generally are similar to those of the Herbst®, except for a few differences.[131] Whereas maxillary molar intrusion is a characteristic feature of Herbst® use,[170,130] this finding has not been reported with the MARA. Although it has been demonstrated that the MARA and Herbst® appliances both produce significant change with respect to controls in the horizontal position of the mandibular incisors, the MARA has been shown to produce less lower incisal flaring.[131]

The anteroposterior treatment effect of the MARA is achieved through both skeletal and dental changes. Skeletal changes indicate that the MARA produces increases in mandibular length, but exerts negligible skeletal effects on the maxilla. In contrast, dental changes seen are due mainly to the distalization of the maxillary molar, which is said to be about 75% of the total dental correction.[131] Mesial movement of the mandibular molar accounts for approximately 25% of the total dental correction.

Due to the MARA's design, possible undesirable dental movements should be considered. In the sagittal plane, distal rotation of upper molars and/or mesial rotation of the lower molars may be observed. These movements may be controlled by incorporation of additional support into the design of the MARA (e.g., a TPA or a lower lingual holding arch). In the vertical dimension, a relative intrusion of the molars due to impingement of the freeway space often is observed following removal of the stainless steel crowns. This phenomenon is short-lived, however, and often self-corrects in a short period of time.[131] Overall the appliance works well in correcting Class II problems. The biggest drawback to using the MARA, however, is appliance breakage and initial patient perception of bulk, which can be a significant problem (at least in our hands).

The Twin Block Appliance. Our choice of functional appliance selection for mixed dentition patients has changed during the past decade, following our increased clinical experience with the twin block appliance. This appliance, developed over 30 years ago by Clark,[132,133,171] is composed of maxillary and mandibular removable acrylic components that fit tightly against the teeth, alveolus, and adjacent supporting structures (Figure 14-36). Interproximal clasps are used bilaterally to anchor the maxillary appliance to the first permanent molars and premolars.

The maxillary occlusal view of the twin block appliance is shown in Figure 14-37. We have modified the design of the twin block appliance slightly by adding a second midline screw in the midsagittal region of the appliance. Our experience has shown that in those patients in whom significant expansion is desired during twin block treatment, the appliance becomes unstable and too flexible if only one midline screw is used. Each screw is activated once per week (about 0.2 mm) until adequate expansion is attained. Clasps are used to secure the appliance to the first molars.

In the lower arch, Clark[133] has recommended the use of a series of ball clasps that lie in the interproximal areas between the canines and lower incisors. We have

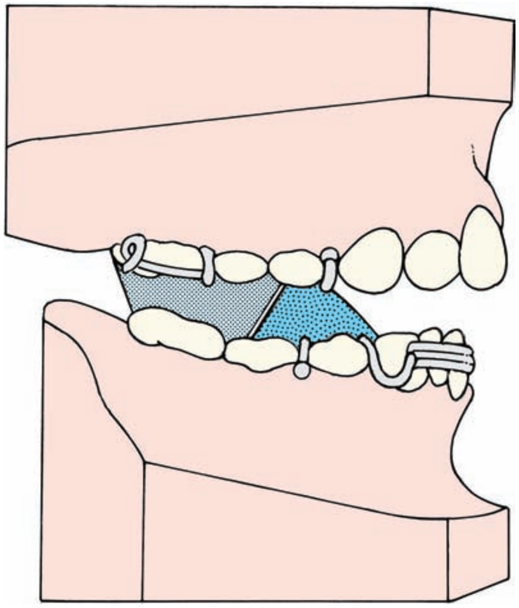

FIGURE 14-36 Sagittal view of the twin block appliance. A labial bow to which clear acrylic has been added increases the anterior retention of the lower appliance, especially during the period of the transitional dentition. The angled interface between maxillary and mandibular appliances guides the mandible into a forward position.

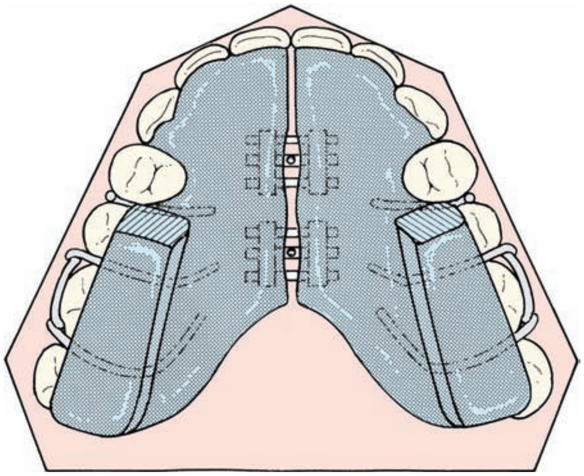

FIGURE 14-37 Maxillary occlusal view of the twin block appliance. Two expansion screws are placed in the midline. Delta clasps are used to secure the appliance to the molars posteriorly, whereas ball clasps are used to anchor the plate in the premolar/deciduous molar region.

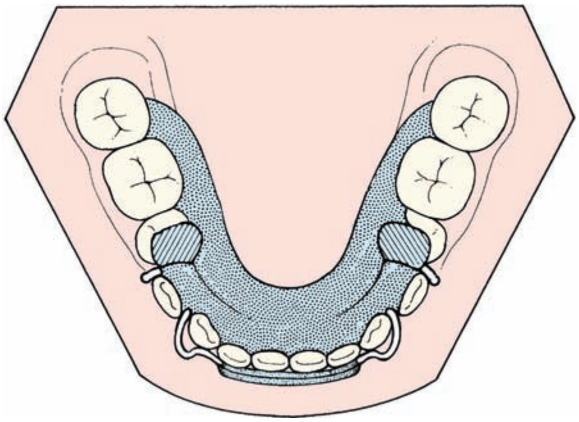

FIGURE 14-38 Mandibular occlusal view of the twin block appliance. Preferred modified design in which the lower lingual acrylic extends posteriorly into the permanent molar region. The lower labial bow with clear acrylic covering extends anteriorly to cover the labial surfaces of the lower anterior teeth. The bite blocks terminate 2 to 3 mm in front of the lower first molar.

modified this design (Figure 14-38) by placing a labial bow anterior to the lower incisors that has labial acrylic similar to that of a lower spring retainer.[172] In contrast to the spring retainer, however, the positions of the lower incisors are not altered in the work model prior to appliance construction.

The twin block appliance has been shown to produce increases in mandibular length as well as variations in lower anterior facial height.[134,135,173] The posterior bite blocks of the twin block appliance can be trimmed to facilitate the eruption of the lower posterior teeth in patients with a deep bite and an accentuated curve of Spee. The blocks also can be left untouched to prevent the eruption of the posterior teeth in patients with a tendency toward an anterior open bite and/or increased lower vertical facial height.

One of the primary reasons why the twin block appliance is indicated in the treatment of Class II malocclusion is a reasonably high level of patient compliance. Because the twin block is composed of two parts, speaking typically is not a problem. The duration of treatment usually is 9 to 12 months, followed by nighttime wear of the appliance or by the use of a stabilization plate to allow for the eruption of the canines and premolars into occlusion. Phase II treatment with fixed appliances usually is begun after the transition to the permanent dentition is complete.

The FR-2 Appliance of Fränkel. In more severe Class II malocclusion patients characterized not only by mandibular skeletal retrusion but significant neuromuscular imbalances, our appliance of choice still is the function regulator (FR-2) appliance (Figures 14-39 and 14-40) of Fränkel.[78,92,124,174] Of all the "functional appliances," the FR-2 appliance is unique in that it is primarily tissue-borne rather than tooth-borne. The base of operation is the maxillary and mandibular vestibule, and the appliance has a direct and primary effect on the neuromuscular system.

The orthopedic principles of Roux[175] have been incorporated into the design of the Fränkel appliance. The appliance first is used as an exercise device in retraining the associated musculature and indirectly producing changes in skeletal and dentoalveolar relationships by reprogramming the central nervous system. In contrast to virtually every other type of functional appliance, the FR-2 appliance interrupts abnormal patterns of muscle activity and ultimately produces an environment in which skeletal and dental arch changes occur spontaneously. Not only have increases in mandibular length been noted following FR-2 treatment,[2,23,78,130,176] but also changes in the transverse dimensions of the dental arches have been reported,[56,78,93,125] due in part to the shielding effect of the vestibular shields (see Figures 14-39 and 14-40) on the associated soft tissue.

In patients with mandibular skeletal retrusion who also show significant neuromuscular imbalances (e.g., hyperactive mentalis, hypertonic buccal musculature), the FR-2 appliance is particularly useful. For example, the lower labial pads (see Figure 14-39) help interrupt hyperactive mentalis activity, a clinical sign of lip incompetence. Fränkel and Fränkel[78] stress the importance of maintaining an adequate lip seal as a key element of successful orthopedic treatment. By balancing the neuromuscular environment, not only can severe malocclusions be treated successfully, but also the tendency toward relapse is minimized, because the neural and soft tissue factors associated with a skeletal malocclusion have been addressed as well. Because the appliance is tissue-borne rather than tooth-borne, maximum skeletal change can be achieved with minimal unwanted tooth movement. The bite registration usually is taken with the mandible 3 to 5 mm ahead of centric occlusion. Fränkel and Fränkel[78] advocate a step-by-step advancement of the appliance in order to minimize unwanted dentoalveolar adaptations (e.g., lingual tipping of upper incisors, flaring of lower incisors).

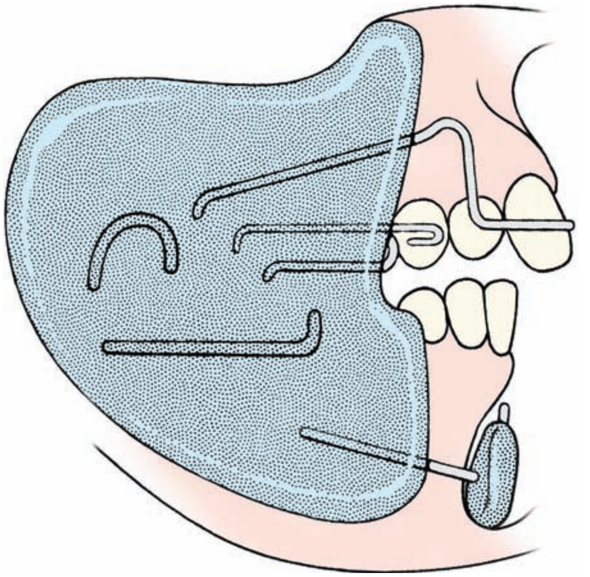

FIGURE 14-39 The lateral view of the function regulator (FR-2) of Fränkel. The base of operation is the maxillary and mandibular vestibules. The appliance has a direct effect on the postural activity of the masticatory and perioral musculature, producing a change in mandibular postural position.

This appliance is especially effective in patients with either a neutral or short lower anterior facial height, because the use of this appliance can lead to an increase in lower facial height during treatment, if indicated. This appliance also is used on patients with excessive vertical development, although care must be taken not to open the bite during treatment. In these patients in particular, a strict regimen of lip seal exercises[1,78,177] must be undertaken. Lip seal training should be used as an adjunct to functional jaw orthopedics, regardless of appliance type, in the same way physical therapy is used in general orthopedics.

Treatment with the function regulator of Fränkel usually is initiated during the middle to late mixed dentition period, although earlier intervention is indicated in patients with severe neuromuscular problems. The duration of active treatment typically is 18 to 24 months, and FR treatment usually is followed by a comprehensive phase of fixed appliance therapy to align and detail the permanent dentition. The description of the precise clinical management of this technically demanding appliance is found in Fränkel and Fränkel[78] and summarized by McNamara and Brudon.[56,178]

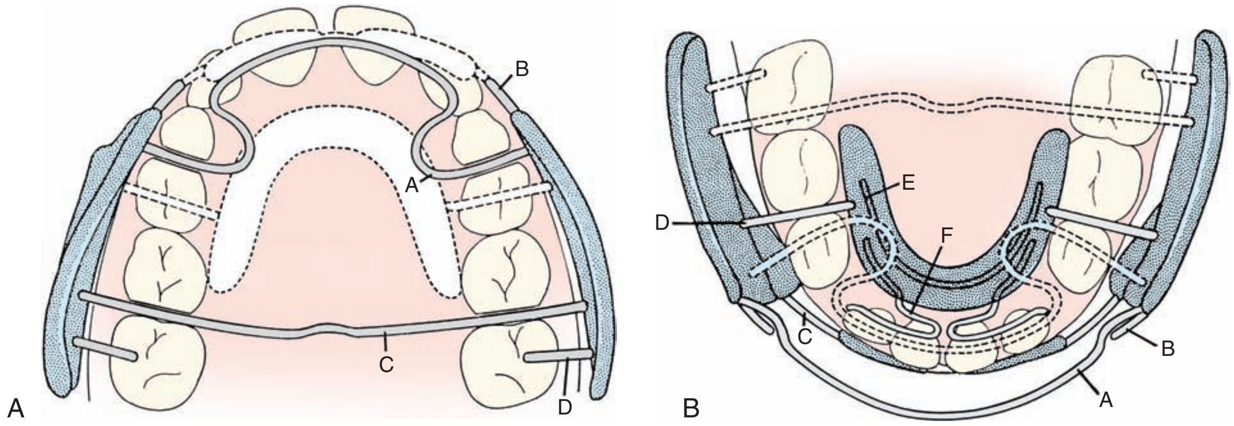

FIGURE 14-40 The function regulator (FR-2) of Fränkel. **A,** Maxillary view. **B,** Mandibular view. Spontaneous expansion of the dental arches usually occurs due to the effect of the vestibular shields and the lower labial pads on the soft tissue. *(Adapted from McNamara and Brudon.[1])*

Treatment Timing for Class II Malocclusion

As mentioned earlier, one of the major changes that has occurred during the past 25 years has been an alteration in the timing of treatment using functional appliances. An early study by our group[23] indicated that, when comparing two cohorts of patients who were treated with the FR-2 appliance of Fränkel, those patients who began treatment at an average of 11.5 years showed a greater mandibular growth response than did patients beginning treatment at approximately 8.5 years of age. The reason for this increased growth response may be related to the synergistic interaction between a change in function, produced by the functional appliance, and growth hormone and related substances that are in greater quantity during the circumpubertal growth period.

A follow-up study by Franchi and Baccetti[179] that considered CVM stages (CS-1 and CS-2 versus CS-3 and CS-4) of the same populations also showed substantially more mandibular growth in those patients receiving FJO treatment during the circumpubertal growth period than earlier when the treated samples were compared with their matched controls. The interaction between altered function and growth hormone also has been demonstrated in the experimental studies of Petrovic and co-workers,[22] among others.

In general, the onset of functional jaw orthopedic therapy in the mild to moderate Class II patient typically is delayed until the middle or end of the mixed dentition. It is our intention to schedule FJO treatment so that this treatment will be followed immediately by a comprehensive phase of fixed appliance therapy. In patients with a significant overjet and mandibular skeletal retrusion, treatment with the cantilever-type Herbst appliance or twin block appliance may be initiated in the early mixed dentition as a single appliance or as part of a more comprehensive protocol that includes RME, prior to the eruption of the permanent dentition. In instances of significant neuromuscular imbalances, however, the FR-2 appliance is the appliance of choice.

Additional Comments Regarding Class II Treatment

There is no one ideal method of treating all Class II malocclusions. Following a thorough clinical examination, a precise analysis of both the cephalometric radiographs and the dental casts should be undertaken to identify the components of malocclusion that make an individual patient unique. After a thorough diagnosis has been established, the clinician can select the appropriate treatment regimen from a wide variety of available treatment modalities.

In recent years, following our experiences using RME (in about 50% of our growing patients) and observing spontaneous improvement of some Class II problems, the use of FJO appliances has decreased in frequency as compared with 10 to 15 years ago (now less than 5%). It has been the author's experience that patient cooperation in wearing removable orthopedic appliances over long periods has become more difficult to secure as children's activities remove them from the home environment and parents provide less appliance wear monitoring. Because true maxillary skeletal protrusion patients are observed relatively infrequently[105] and noncompliance treatments have become available, negating concerns with lack of cooperation, extraoral traction is a minimally used treatment option. With any of the therapeutic approaches requiring patient compliance, a very positive approach by the orthodontist coupled with solid parental support is usually required for success.

TREATMENT OF CLASS III MALOCCLUSION

One of the most difficult types of malocclusions to treat is a Class III malocclusion. The occurrence of an end-to-end incisor relationship or a frank anterior crossbite is identified easily by both the family practitioner and the parent as an abnormal occlusal relationship. Thus, it is common for Class III patients to be referred for early treatment. The outcome of various early treatment protocols may or may not be successful, however, depending on the severity of the problem, the familial malocclusion and respiratory histories of the patient, and the age at which treatment is initiated.

Components of Class III Malocclusion

Class III malocclusion occurs in about 1% of the North American population,[180–183] and Class III patients comprise about 5% of the typical orthodontic patient load in the United States.[184] This type of malocclusion is far more prevalent in other regions of the world, particularly in Pacific Rim countries. Thus, the treatment of Class III problems comprises a significant portion of orthodontic and orthopedic treatment in such countries as Japan, Taiwan, and Korea.

Class III malocclusion does not encompass a single diagnostic entity. Rather it can be due to maxillary skeletal retrusion, mandibular skeletal protrusion, or a combination of the two.[185–189] As with all malocclusions that are considered by the Angle classification system, Class III malocclusions include a variety of skeletal and dental components that may vary from our concept of normal or ideal in all three dimensions.

Available Class III Treatment Strategies

Before discussing early treatment strategies, it is important to review briefly the usual approach to the correction of Class III malocclusions in an adolescent or adult patient. When a patient first is diagnosed as having a Class III malocclusion in the permanent dentition, treatment options are limited, particularly if there is a strong skeletal component to the Class III occlusal relationship. Such treatment usually includes comprehensive orthodontic therapy, either combined with extractions and/or orthognathic surgery.

The orthognathic surgical procedure is designed to address the imbalance of the skeletal component (e.g., sagittal split osteotomy or vertical ramus osteotomy to posteriorly reposition the mandible in instances of mandibular prognathism, LeFort I advancement in instances of maxillary skeletal retrusion—procedures in both jaws may be used in instances of severe maxillomandibular skeletal imbalances.) In other words, the surgical procedure is designed to correct whatever skeletal imbalances are present, as is the case with a late adolescent or adult Class II patient. In patients in whom significant skeletal growth is anticipated, the surgical procedure is deferred until the end of the active growth period. Such patients, however, still face the psychosocial problems during childhood and teen years that have been shown to be associated with this type of malocclusion.[190]

The treatment of Class III malocclusion in the mixed dentition (or late deciduous dentition) can be approached from a slightly different conceptual viewpoint. It is possible to select a treatment protocol that is intended to address the skeletal imbalance in a Class III mixed dentition patient. For example, Fränkel[78,191] recommends the function regulator (FR-3) appliance in patients whose malocclusion is characterized primarily by maxillary skeletal retrusion. On the other hand, the orthopedic chin cup[6,7,192–194] has been used in patients whose malocclusions are characterized primarily by mandibular prognathism, a procedure that has its greatest effect when used in primary and early mixed dentition patients. The orthopedic facial mask that has been popularized by Delaire[195–197] and refined by Petit[198–200] is the appliance most widely used in the United States today. Each of these treatments has been shown to produce favorable effects in Class III patients, but the long-term outcomes have been variable. Also, there are substantial differences with regard to the speed of correction and in the regions of the craniofacial complex that are affected.

Appliance Selection

A basic axiom of orthodontic treatment is that the treatment approach should be designed to address the specific nature of the skeletal and/or dentoalveolar imbalance. This axiom is illustrated by the selection of the specific surgical procedure or procedures used in the correction of a Class III malocclusion in an adolescent or adult patient. In patients with a Class II malocclusion, it also is demonstrated by the selective use of extraoral traction in the correction of maxillary prognathism and of functional jaw orthopedics in the correction of mandibular retrusion. An exception to this rule may be the treatment of the developing Class III malocclusion.

The Orthopedic Facial Mask. Of the three mixed dentition treatment strategies discussed earlier, the orthopedic facial mask (Figure 14-41) has the widest application and produces the most dramatic results in the shortest period of time. Thus, the orthopedic facial mask is our customary appliance of choice for most Class III patients seen in the early mixed dentition or late deciduous dentition. The use of this single regimen in most early Class III patients seems arbitrary and paradoxical at first glance, given the various combinations of skeletal and dental components of Class III malocclusions in mixed dentition patients.[185,201] Because intervention using an orthopedic facial mask is undertaken at such an early age, however, the treatment effects produced by the facial mask ultimately are incorporated into the future craniofacial growth of the patient that occurs over a long period of time. Because the appliance system affects virtually all areas contributing to a Class III malocclusion (e.g., maxillary skeletal retrusion, maxillary dentoalveolar retrusion, mandibular prognathism, decreased lower anterior facial height), by manipulating force vectors, this treatment protocol can be applied effectively to most developing Class III patients regardless of the specific etiology of the malocclusion.

The orthopedic facial mask system has three basic components: the facial mask, a bonded maxillary splint, and elastics. The facial mask (see Figure 14-41) is an extraoral device that has been modified by Petit[199] and now is available commercially (Great Lakes Orthodontic Products, Tonawanda, NY). In essence, the facial mask is composed of a forehead pad and a chin pad that are connected by a heavy steel support rod. To this support rod is connected a crossbow to which are attached rubber bands to produce a forward and downward elastic traction on the maxilla. The position of the pads and crossbow can be adjusted simply by loosening and tightening set screws within each part of the appliance.

Although Petit[199] has recommended a number of different intraoral devices, both fixed and removable, to which the elastics can be anchored, it is our strong preference to use a bonded maxillary expansion appliance that is similar in design to that discussed previously in the treatment of arch length discrepancy problems. The major modification in the splint design is the addition of facial mask hooks in the region of the maxillary deciduous first molar (Figure 14-42).

Even though the orthopedic facial mask has been available for more than 100 years,[202–204] surprisingly few studies have dealt with the treatment effects produced by the facial mask. Until recently,[205–209] most published studies dealing with facial mask therapy have been anecdotal in nature.[210–214] It appears that the facial mask, especially when combined with a rigid maxillary anchorage unit (e.g., a bonded acrylic splint expander) that unlocks the occlusion, can produce one or more of the following treatment effects:

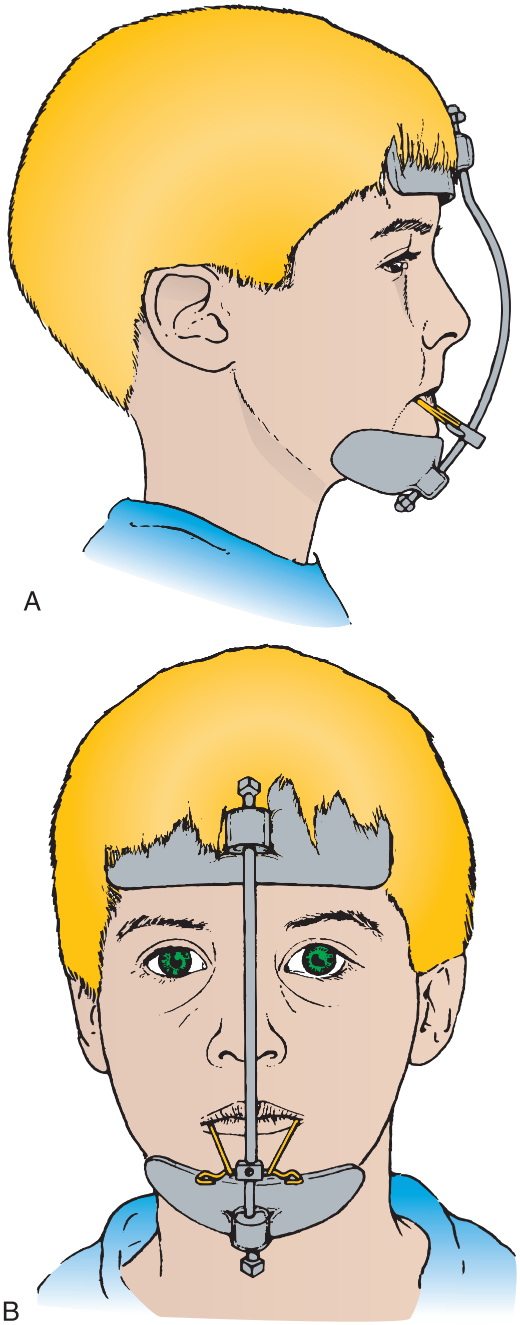

FIGURE 14-41 The orthopedic facial mask of Petit. **A,** Lateral view. **B,** Frontal view. This appliance, best used in patients in the early mixed dentition, is worn on a full-time basis for about 6 months, after which it can be worn on a night-time basis as a retention appliance. The elastics are connected to a bonded maxillary splint (see Figure 14-41), to which have been attached hooks in the upper first deciduous molar region. The angle of elastic pull from the horizontal will affect the amount of vertical versus horizontal movement. In overclosed patients, the downward angle is greater, whereas in patients with excessive vertical height, the pull is more parallel to the Frankfort horizontal plane. The most common is 15 to 20 degrees downward from the Frankfort horizontal plane.

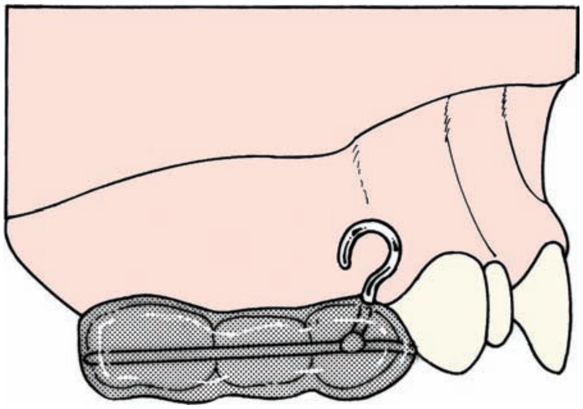

FIGURE 14-42 The bonded maxillary acrylic splint (lateral view). The hooks for the elastics usually are placed adjacent to the upper first deciduous molars. *(Adapted from McNamara and Brudon.[1])*

1. Correction of a CO-CR discrepancy, a shift in occlusal relationship that is immediate and usually is associated with pseudo–Class III patients
2. Maxillary skeletal protraction, with 1 to 2 mm of forward movement of the maxilla often (but not always) observed
3. Forward movement of the maxillary dentition
4. Lingual tipping of the lower incisors, particularly in patients with a preexisting anterior crossbite
5. Redirection of mandibular growth in a downward and backward direction, resulting in an increase in lower anterior facial height[208,209,215]

Once the decision has been made to use an orthopedic facial mask, the first step of the appliance therapy is the fabrication and bonding of the maxillary splint (see McNamara and Brudon[1] concerning the technical details). The splint is activated ¼ mm once-per-day at bedtime until the desired increase in maxillary width has been achieved. In patients in whom no increase in transverse dimension is desired, the appliance still is activated for 8 to 10 days to disrupt the maxillary sutural system and to promote maxillary protraction.[45]

After the patient has become accustomed to wearing the maxillary splint, facial mask treatment is initiated. A sequence of elastics of increasing force (200, 350, 600 grams per side) is used during the break-in period until a heavy orthopedic force is delivered to the maxillary complex. Ideally, the facial mask is worn on a full-time basis (about 20 hours per day) for 4 to 6 months, and then it can be worn on a nighttime basis only for an additional period of time. It usually is unwise to have the splint remain bonded in place for longer than 9 to 12 months due to the potential risk of leakage and subsequent decalcification of the underlying dentition.

The ideal stage of dental development during which to begin facial mask therapy is at the eruption of the permanent maxillary central incisors. Usually, the lower incisors already have erupted into occlusion. Achieving a positive horizontal and vertical overlap of the incisors during treatment is essential in providing an environment that will help maintain the achieved anteroposterior correction of the original Class III malocclusion. In patients with mild to moderate Class III problems, a positive overjet of 4 to 5 mm is achieved prior to the time that the facial mask is discontinued. It is anticipated that there will be some regression of the overjet relationship during the early posttreatment period. Every effort should be made, however, to maintain a positive overbite and overjet relationship throughout the retention period.

After the facial mask and the RME appliance have been removed, the patient can be retained using a number of appliances, including a simple maintenance plate (see Figure 14-17), an FR-3 appliance of Fränkel, or a chin cup. Because the facial mask usually is used in the early mixed dentition, a substantial amount of time may elapse before the final phase of fixed appliance treatment can be initiated. *Multiple stages of orthopedic intervention may be required*, and thus these patients must be monitored until all major facial growth is completed.

The FR-3 Appliance of Fränkel. An intraoral appliance that has been used quite effectively in the treatment of Class III malocclusions in the mixed dentition is the function regulator FR-3 appliance of Fränkel.[78,176,191,216,217] Of all the Fränkel appliances, the FR-3 appliance (Figure 14-43) perhaps is the easiest to manage clinically because there is no substantial postural change produced in the maxillomandibular relationship. As with all of Fränkel's appliances, the base of operation of the FR-3 appliance is the maxillary and mandibular vestibules. The appliance is designed to restrict the forces of the associated soft tissue on the maxillary complex (see Figure 14-43), transmitting these forces through the appliance to the mandible.

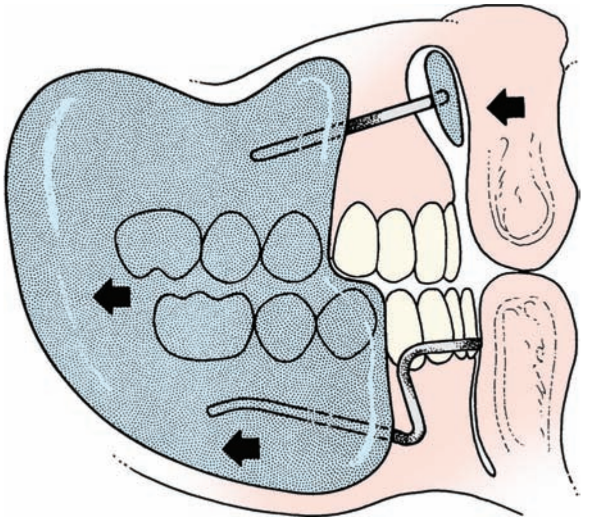

FIGURE 14-43 The FR-3 appliance of Fränkel. The vestibular shields and the upper labial pads shield the maxillary alveolus from the forces of the surrounding soft tissue. These forces are transmitted through the appliance to the mandible. *(Adapted from McNamara and Brudon.[1])*

A major advantage in using the FR-3 appliance of Fränkel is that it is relatively inconspicuous, especially in comparison to the orthopedic facial mask or chin cup. The FR-3 is worn intraorally, and often wearing the appliance actually improves the appearance of the patient by filling out the upper lip region in individuals with substantial maxillary skeletal retrusion. This appliance is worn easily by the patient. Interestingly, the treatment effects produced by the FR-3 appliance have been shown to be similar to those produced by the orthopedic facial mask.[78,216–219]

A major difference between the FR-3 appliance and the orthopedic facial mask is the duration of treatment. In a routine Class III patient, the orthopedic facial mask may produce a correction of the malocclusion within the first 6 months after initiating treatment. Normally, 12 to 24 months are necessary to produce a similar response with the FR-3 appliance. It is obvious, however, that the FR-3 appliance has much more of an effect on the associated soft tissue, particularly on any existing hyperactivity in the muscles associated with the maxilla, than does the facial mask. This appliance was designed by Fränkel, based again on the principles of Roux,[175] in that the primary action of the appliance is on the associated soft tissue, hopefully leading to a reprogramming of the central nervous system and a retraining of the craniofacial musculature.

When used as the primary appliance, the FR-3 is worn for about 20 hours per day, with the patients removing the appliance only during such activities as eating and playing contact sports. If the appliance is worn as a retainer following either full-time FR-3 therapy or facial mask therapy, it usually is worn only during the nighttime hours.

The Orthopedic Chin Cup. The oldest of the orthopedic approaches to the treatment of Class III malocclusion is the chin cup. The effects of this appliance have been investigated thoroughly,[7,192,193,220–223] with much of the research conducted on Asian populations due to the higher incidents of Class III malocclusion in these groups.[6,222,224–226]

Although there are a wide variety of chin cup designs available commercially, in general these appliances can be divided into two types. The *occipital-pull chin cup* is used in instances of mandibular prognathism, and the *vertical-pull chin cup* is used in patients with steep mandibular plane angles and excessive lower anterior facial height.

The occipital-pull chin cup (Figure 14-44, *A*) frequently is used in the treatment of Class III malocclusions. This type of chin cup is indicated for use in patients with mild to moderate mandibular prognathism. Success is greatest in those patients in the deciduous and mixed dentition who can bring their incisors close to an edge-to-edge position when in centric relation. This treatment

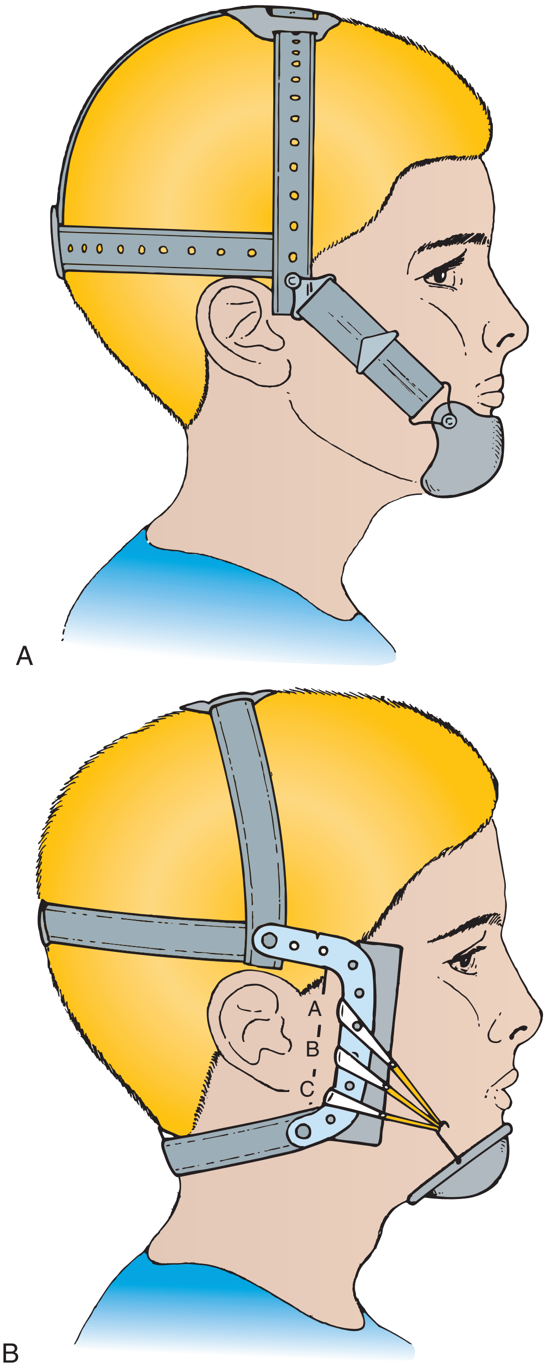

FIGURE 14-44 The occipital-pull chin cup. **A,** Soft elastic appliance. The direction of force is determined by the position of the head cap. **B,** Hickam-type headgear. Used as anchorage for a hard chin cup. The direction of pull can be adjusted according to the placement of the elastics (*A–C*). *(Adapted from McNamara and Brudon.*[1]*)*

is useful particularly in patients who begin treatment with a short lower anterior facial height, because this type of treatment can lead to an increase in this dimension. If the pull of the chin cup is directed below the condyle, the force of the appliance may lead to a downward and backward rotation of the mandible. If no opening of the mandibular plane angle is desired, the force should be directed through the condyle to help restrict mandibular growth. The use of a Hickham-type headcap combined with a hard chin cup (Figure 14-44, *B*) allows for variable vectors of force to be produced on the lower jaw.

If no increase in lower anterior facial height is desired, the vertical-pull chin cup can be used (Figure 14-45, *A*). Pearson[227–230] has reported that the use of a vertical-pull chin cup (VPCC) can result in a decrease in the mandibular plane angle and the gonial angle and an increase in posterior facial height in comparison with the growth of untreated individuals. This type of extraoral traction can be used not only in individuals who have a Class III malocclusion, but also for any patient in whom an increase in the anterior vertical dimension is not desired. A recent study by Schulz and co-workers[231] that compared the vertical-pull chin cup combined with the bonded acrylic splint expander to the bonded expander used alone in high-angle patients indicated that a modest improvement can be obtained in the mandibular plane angle and in lower anterior facial height with the use of the vertical-pull chin cup. They noted, however, that the effect of the vertical orthopedic treatment was observed only during early Phase I therapy, not during comprehensive fixed appliance treatment.

It is difficult to create a true vertical pull on the mandible due to the problems encountered in anchoring the appliance cranially. One of the easiest of the vertically directed chin cups to manipulate clinically is shown in Figure 14-45, *A*. A padded band extends coronally and is secured to the posterior part of the head by a cloth strap. A spring mechanism is activated by pulling the tab inferiorly and attaching the tab to a hook on the hard chin cup.

Another type of chin cup that produces a vertical direction of force is shown in Figure 14-45, *B*. This appliance incorporates a cloth headcap that curves around the crown of the head and is secured posteriorly with two horizontal straps. A throat strap also secures the appliances to the head of the patient. This particular design is useful in those patients in whom anchorage in the cranial region is difficult to achieve. Either of these designs may be modified further with the construction of a custom chin cup that may be fabricated from acrylic. If customized, the attachment hook may be placed more to the posterior of the cup, closer to the throat angle, providing a more effective vertical direction of pull.

One of the substantive concerns regarding chin cup therapy is whether the growth of the mandible can be retarded through wearing a chin cup. Sakamoto and co-workers[226] and Wendell and co-workers[232] have noted decreases in mandibular growth during treatment. Wendell and associates, when examining a group of Class III patients treated in the mixed dentition, noted that the mandibular length increases in the treated group were only about two-thirds of those observed in the control group of mixed dentition individuals who

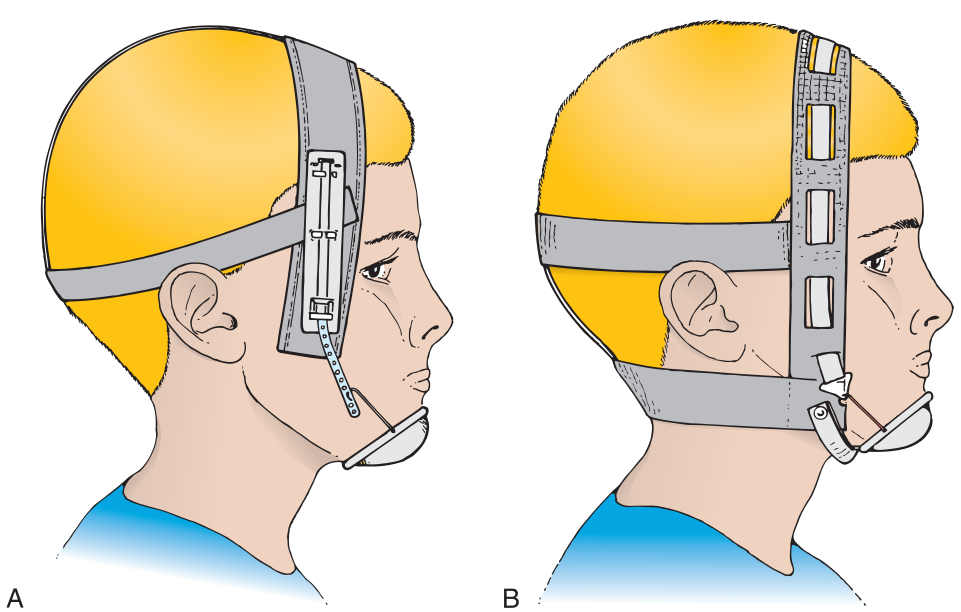

FIGURE 14-45 The vertical-pull chin cup. **A,** Unitek design. A spring force design is used to create a vertical direction of pull. **B,** Summit Orthodontics design. A cloth head cap curves around the crown of the head and is secured posteriorly with two horizontal straps. The force is produced by the stretch of the elastic material. In both of these examples, a hard chin cup is shown. *(Adapted from McNamara and Brudon.[1])*

received no treatment. Mitani and Fukazawa,[233] however, noted no differences in mandibular length in Class III individuals who began treatment during the adolescent growth period in comparison with control values. In addition, in a recent study of long-term adaptation to the chin cup, Sugawara and Mitani[223] noted that such treatment seldom alters the inherited prognathic characteristics of skeletal Class III profiles over the long term. Changes in the vertical direction of mandibular growth, however, have been noted. L. W. Graber[7] reported that, in a sample of young Class III patients, the predominantly horizontal mandibular growth pattern was redirected more vertically, indicating that the orthopedic chin cup can produce an increase in lower anterior facial height while correcting the anteroposterior malrelationship.

It has been our observation that chin cup works best when needed least, that is, when the adverse mandibular growth has been mild to moderate in nature. The earlier the problem is addressed, the more successful treatment appears to be. Multiple "stages" of active chin cup home wear are often required in order to be successful in the case of moderate prognathism. Thus even the "corrected" patients need to be monitored at 4- to 6-month intervals until major growth has ceased.

Additional Comments Regarding Class III Treatment

As discussed previously, the appearance of Class III malocclusion is relatively easy to identify in young patients. Yet, the treatment of this occlusal problem is fraught with many difficulties. Fortunately, the level of patient cooperation in the young mixed dentition patient generally is excellent, and thus satisfactory compliance usually is achieved.

Of the three treatment modalities considered in this section, the orthopedic facial mask combined with a bonded maxillary splint seems most applicable in the routine Class III patient. This type of appliance produces treatment effects in both skeletal and dentoalveolar aspects of the craniofacial complex. Given a young patient, the resolution of the underlying Class III relationship occurs relatively quickly (4 to 6 months), and then the mask can be worn for an additional period as a retainer at night before the bonded maxillary splint is removed.

The FR-3 appliance of Fränkel can be used either as a primary interceptive appliance or as a retainer. This treatment regimen makes the most biological sense, because the primary focus of this therapy is on the soft tissue, particularly the musculature, which in part may have been the etiology of the Class III relationships. The FR-3 appliance is less intrusive to the everyday life of the patient but may take two or three times as much treatment time to achieve correction of the malocclusion. The FR-3 appliance also can be used as a retention appliance following orthopedic facial mask or chin cup therapy.

Because mandibular growth exceeds maxillary growth during adolescence, early Class III correction may be lost during the teenage years. Indeed, orthopedic appliances may be required during the typical "retention" stage of treatment, particularly in males where mandibular growth often continues well after fixed orthodontic appliances are removed. At the onset of any interceptive treatment the patient and parents should be advised of the possibility of multiple stages of orthopedic intervention as well as the potential need for surgical correction. The wise clinician never makes guarantees regarding the treatment of Class III malocclusion because the outcome of any individual Class III patients is very difficult to estimate. We agree with T. M. Graber,[234] Sakamoto,[226] and Sugawara and co-workers,[6] who advocate the treatment of Class III malocclusion as early as is practical. Primary dentition chin cup treatment may be started to intercede in a developing Class III with subsequent maxillary protraction as the patient matures.

There is one other treatment protocol for early correction of Class III malocclusion on the horizon. DeClerck and colleagues[235–239] have shown positive results when using bone anchors in combination with full-time wear of Class III elastics. The mini-plates are attached with two or three screws a safe distance from the roots of the teeth, facilitating true bony rather than dental anchorage. Although to this point, their results primarily are in the case report stage, their treatment outcomes are dramatic and appear promising.[238–241]

SUMMARY

An attempt has been made in this chapter to synthesize a coherent approach to orthodontic and orthopedic treatment, making available to the orthodontist a variety of early and late treatment protocols. Virtually all orthodontists are well versed in the management of the adolescent and adult patient. Many orthodontists, however, are uncomfortable (and perhaps a bit skeptical, given the controversy) about mixed dentition treatment.

Although this latter topic has been addressed in many of the orthodontic texts since the beginning of the past century, mixed dentition treatment generally has been considered as secondary or peripheral to full banded or bonded appliance therapy in the adolescent or adult patient. By taking advantage of many of the newer technologies available, especially the bonded acrylic splint expander, the Herbst appliance, and the Pendex appliance, we have attempted to provide the reader with a conceptual framework on which the selection and timing of various treatment modalities can be based.

A few concluding comments should be made on the basis of our own clinical experiences. Some of these comments are obvious; some are not.

1. The timing of orthodontic and orthopedic treatment protocols varies with the underlying nature of the malocclusion. Some problems respond well to early intervention, others to late treatment. The selection of specific protocols and when to use them should be based on evidence derived from rigorous prospective and retrospective clinical studies.
2. Implicit in initiating early treatment is that the overall treatment time of the patients will be extended from the normal 2 or 3 years generally needed for comprehensive treatment of the adolescent patient. Initiating treatment in the mixed dentition, however, does not imply that treatment will be provided continuously from the time of eruption of the permanent incisors until the time that the permanent second molars are aligned with fixed appliances. We have tried to structure our treatment protocols so that typically a concentrated period of early treatment is initiated, generally in the early mixed dentition. There is a defined beginning of the treatment and a defined ending of the treatment that is known to the patient and to the parents before the protocol is started.
3. Intermittent observation of the patient during the transition of the dentition is a prime component of early treatment. We generally prefer to see our patients every 4 to 6 months after the first phase of treatment is completed. The appliances used during this time are simple, usually only a removable palatal plate typically without a labial wire that is worn full-time for at least 1 year. Monitoring the patient on an intermittent basis allows the clinician to take advantage of the transition of the dentition, particularly in the second deciduous molar regions. It also allows observation of an adverse growth spurt and the opportunity to intercede as needed.
4. Passive holding arches (i.e., TPA, lingual arch) should be placed prior to the loss of the second deciduous molars in most early treatment patients. Not only will the leeway space be maintained (i.e., on average 2.5 mm unilaterally in the mandible, 2.0 mm unilaterally in the maxilla), but also maxillary molar rotation and uprighting can be achieved at the same time.
5. Most patients undergoing early treatment will require a final phase of fixed appliances. Usually the treatment time is reduced to about 12 to 18 months, because the majority of patients undergoing comprehensive therapy will be treated as nonextraction patients with Class I or near Class I molar relationships. Parents must be informed at the start and reminded at the end of mixed dentition treatment that a second stage of orthodontic treatment will be required after permanent teeth erupt.
6. Initiating early treatment does not imply that all patients treated in the mixed dentition will avoid the extraction of permanent teeth. It has been our experience that even in those patients in whom orthopedic expansion protocols are initiated, the extraction of permanent teeth (usually premolars) is necessary in about 10% of these patients. In some instances, orthopedic expansion of the maxilla is initiated to “broaden the smile” in patients with severe maxillary constriction, and subsequently permanent teeth are extracted as part of the overall treatment protocol.

7. We have emphasized the importance of treatment timing in Class II malocclusion. In most Class II patients seen in the mixed dentition, we often start early treatment by managing the transverse dimension, with definitive Class II treatment rendered (if necessary) at the time of the circumpubertal growth period (the "spontaneous improvement" in Class II malocclusion is a frequently occurring phenomenon). Only in instances of a "socially handicapping" malocclusion will definitive Class II intervention be undertaken by us in the early mixed dentition.
8. Early treatment will not eliminate the need for corrective jaw (orthognathic) surgery in all patients with severe skeletal and neuromuscular imbalances. Functional jaw orthopedics or maxillary distalization can be used to minimize substantially the sagittal maxillomandibular imbalance, but it may be impossible to eliminate this imbalance entirely without compromising the facial aesthetics of the individual. In these instances, orthognathic surgery in combination with fixed appliances is the treatment of choice. The need for orthognathic surgery also is obvious in patients with a Class III malocclusion characterized by significant skeletal imbalances, especially in those with a family history of significant Class III malocclusion. There may well be, however, a psychological benefit for both child and parent in reducing a malocclusion and providing an "interim" aesthetic smile, knowing that orthognathic surgery for skeletal balance may or will be required after growth has been completed.
9. Patient compliance usually is excellent in patients treated in the mixed dentition, particularly if the appliance that is selected requires no or minimal patient cooperation other than that usually associated with a routine orthodontic treatment (e.g., good oral hygiene, diet control, and wearing of retainers). By initiating treatment in the mixed dentition, many of the skeletal and dentoalveolar problems associated with malocclusion often are eliminated or reduced substantially, thus lessening the need for prolonged fixed appliance therapy in the adolescent years.

In summary, we have attempted to provide an overview of various early and late treatment protocols that may be appropriate for certain orthodontic patients within a given practice. As with all such technologies, each of these protocols should be evaluated with healthy skepticism and should be initiated slowly until the parameters of success and failure are clearly established. The protocols outlined in this chapter have been used routinely by us for decades and have proved to be satisfactory if approached within a framework of common sense and with a thorough understanding of comprehensive orthodontic biomechanics. Routine fixed appliance therapy is characterized by a series of "individual specific midcourse corrections," and our type of treatment is no different. Observation and diagnosis that will influence treatment is never static.

Finally, it must be stressed that early intervention is not always necessary or appropriate. In some instances, early treatment does not change appreciably the environment of dentofacial development and permanent tooth eruption. In such instances, early treatment may serve only to increase treatment time and cost and may result in a lack of patient cooperation in later years. If every effort is made, however, to time the treatment appropriately so as to maximize the treatment benefit in the shortest period of time, and if the implemented treatment protocol has a reasonably predictable duration and outcome, orthodontic and orthopedic intervention can be provided successfully.

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We also must recognize the enormous contributions of Drs. Tiziano Baccetti and Lorenzo Franchi of the University of Florence, whose work has been cited throughout this chapter. Their insights have influenced our approach to treatment timing through a series of evidence-based clinical studies that have been published jointly with us since the mid 1990s.

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CHAPTER

15

Standard Edgewise: Tweed-Merrifield Philosophy, Diagnosis, Treatment Planning, and Force Systems

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Nothing worthwhile ever departs.

OUTLINE

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- **Summary**

HISTORICAL PERSPECTIVE

An obsession for order motivated Edward Hartley Angle (Figure 15-1) to create, in 1888, the Angle System. This system ultimately resulted in the introduction of the edgewise multibanded appliance, 5 years before Angle's death, which has been the progenitor of all modern appliances.

THE ANGLE SYSTEM

Edward Angle, after graduation from dental school in 1878 and before his introduction of the Angle System in 1888, experienced many technical problems and frustrations in patient treatment that motivated and inspired him to develop a standard appliance.[2,2a] He believed that an orthodontic appliance must have five properties:

1. Simplicity: It must push, pull, and rotate teeth.
2. Stability: It must be fixed to the teeth.
3. Efficiency: It must be based on Newton's third law and anchorage.
4. Delicacy: It must be accepted by the tissues, and it must not cause inflammation and soreness.
5. Inconspicuousness: It must be aesthetically acceptable.

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FIGURE 15-1 Edward H. Angle.

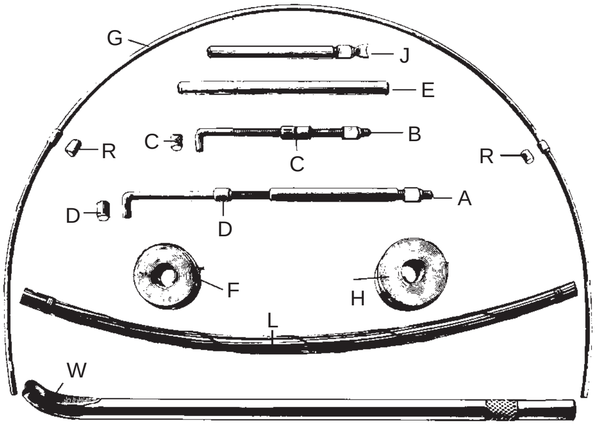


FIGURE 15-2 The basic components of Angle's standard appliance, illustrating traction screws (*A, B*), attachment tubes (*C, D*), jackscrews (*E, J*), lever wires (*L*), band material (*F, H*), archwire (*G*), wrench (*W*), and archwire lock (*R*). *(From Angle EH:* Treatment of malocclusion of the teeth, *Philadelphia, 1907, SS White.)*

Angle designed a standard appliance composed of a specific number of basic components (Figure 15-2). He had these components mass produced so that they could be assembled into a simple, stable, efficient, delicate, and inconspicuous treatment device, without difficulty, in less time and with minimal pain and discomfort to the patient. This universal application enabled practitioners to treat more patients at a higher level of excellence and at less cost than they had done previously. In effect, it was the beginning of a relationship among manufacturers, suppliers, and orthodontists; it was the Angle System.

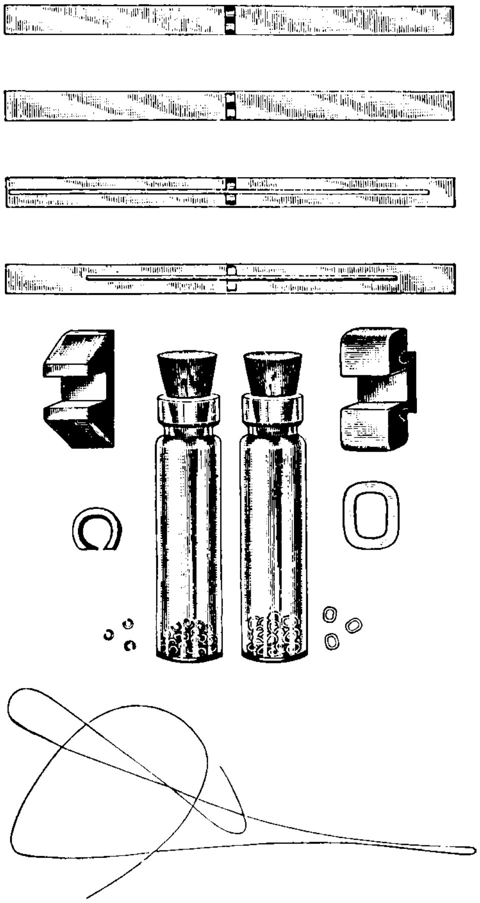


FIGURE 15-3 Original edgewise brackets.

THE EDGEWISE APPLIANCE

Two years before he died, with knowledge born from experience and gained from his other appliance inventions, Angle set out to devise an appliance that would not only overcome past difficulties but also would have a greater chance than did its predecessors of treating to "ideals." He changed the form of the brackets by locating the slot in the center and placing it in a horizontal plane instead of a vertical plane. The archwire was held in position first by a brass ligature and later by a delicate stainless steel ligature. The new edgewise bracket consisted of a rectangular box with three walls within the bracket, 0.022 × 0.028 inch in dimension. The bracket slot opened horizontally (Figure 15-3). This new design provided more accuracy and thus a more efficient torquing mechanism.

Because Angle introduced the edgewise bracket only 2 years before he died, he had little time to teach its manipulation, develop it further, and improve its use—and he knew it.

CHARLES H. TWEED

When Charles H. Tweed graduated from an improvised Angle course given by George Hahn in 1928, he was 33

FIGURE 15-4 Charles H. Tweed.

years old and Angle was 73 (Figure 15-4). Angle was bitterly disappointed by the reception that had been accorded the edgewise appliance. He was infuriated and bitter about the modifications that were being made by several of his graduates (e.g., Spencer Adkinson). To him it was obvious that something had to be done if the edgewise appliance was to survive intact.

Angle decided that an article describing the appliance must be published in *Dental Cosmos*. He asked Tweed to help him with the article because Tweed had just finished the Angle "course" and because he admired and respected Tweed's ability. For 7 weeks they worked together and in the process became close friends. During this time, Angle advised Tweed that he could never master the edgewise appliance unless he limited his practice solely to its use. And so with the completion of the article for *Dental Cosmos*, Charles Tweed returned to Arizona and established in Phoenix the first pure edgewise specialty practice in the United States.

For the next 2 years the two men worked together closely. Tweed diagnosed, treatment planned and treated his patients, and Angle acted as his advisor. Angle was pleased with the results, and he was instrumental in getting Tweed on several programs. During these 2 years, in a series of more than 100 letters, which are now housed in the Tweed Foundation Library, Angle urged his young disciple to carry out two vital requests: (1) to dedicate his life to the development of the edgewise appliance and (2) to make every effort to establish orthodontics as a specialty within the dental profession.

Tweed followed Angle's advice. First, he instigated the passing of the first orthodontic specialty law in the United States. He did this by canvassing patients, persuading dentists, influencing and arousing politicians, speaking at meetings, having petitions signed, and even taking patients before the legislature. In short, it was a one-man blitz. His untiring and relentless efforts were successful, and in 1929 the Arizona legislature passed the first law limiting the practice of orthodontics to specialists. Tweed received Certificate No. 1 in Arizona and became the first certified specialist in orthodontics in the United States.

On August 11, 1930, Angle died at the age of 75. A strange antithesis can be found between the printed lines from Angle,[2] wherein he states, "We are reminded that there is still much to be accomplished before this great subject of orthodontics is unfolded to us in a manner in which we may comprehend it in all its requirements"; and his words, spoken so shortly before death released him from his life's labors: "I have finished my work, it is as perfect as I can make it." Angle must have known, even when he made his last statement on his deathbed, that his work must go on. He must have been at peace with the knowledge that he had found the right man to pursue his endeavors.

In 1932, Tweed published his first article in the *Angle Orthodontist*. It was titled "Reports of Cases Treated with Edgewise Arch Mechanism."[3] Tweed held to Angle's firm conviction that one must never extract teeth. This conviction lasted for 4 short years.

The postreatment facial aesthetics Tweed began to observe in his patients was discouraging to him, so discouraging in fact that he almost gave up orthodontic practice. He knew he had the appliance, and he knew he had the ability, but his results were aesthetically unsatisfactory and unstable. He devoted the next 4 years of his life to the study of his successes and failures. During this 4-year period, he made a most important observation: upright mandibular incisors frequently were related to both posttreatment facial balance and stability of the treated dentition. To position mandibular incisors upright, he concluded that one must, in many instances, extract teeth and prepare anchorage. He selected his failures, extracted four first premolar teeth, and retreated the patients. He did this without charging a fee.

In 1936 Tweed delivered to the membership of the Angle Society and subsequently published his first paper[4,5] on the extraction of teeth for orthodontic malocclusion correction. "Mother" Angle, the editor of the *Angle Orthodontist* and a member of the Angle Society, refused to attend the lecture. George Hahn, the man who went out of his way to create the opportunity for Tweed to take the Angle course, criticized him severely. Angle disciples considered Charles Tweed to be a traitor to the greatest man orthodontics had ever known. Tweed was crushed by the response, but he returned home determined to continue his research.

He worked even harder than before. By 1940, he had produced case reports, with four sets of records, of 100 consecutively treated patients who were first treated with nonextraction and later with extraction. He managed to get himself on the program of the next meeting of the Angle Society in Chicago, where he would present a paper and display his case reports.

Dr. Strang, one of Angle's students in the early years, described the event this way[6]:

> I noted that Dr. Charles Tweed was scheduled to be on the program of the meeting in Chicago. I planned to be there with the objective of lacing into him for violating Dr. Angle's sacred principle of non-extraction in treatment.
>
> Previous to reading his paper, Dr. Tweed had placed on tables before and after casts and photographs of one hundred consecutively treated patients. The results in all of these one hundred patients were magnificent and beyond criticism.
>
> Dr. Tweed read his well-written and illustrated paper. He explained his objective of keeping the teeth over basal bone, which made it necessary to extract teeth in many patients; however, it did produce stable results. Then he sat down. There was no applause. The room filled with shouted demands from the floor. For at least an hour, Charlie got the worst tongue-lashing that you can possibly imagine and not one word of praise for the beautiful results of treatment. Here was a student of Dr. Angle's violating the most fixed and rigid rule in his instruction—never extract teeth.
>
> During all this vicious attack, my mind took a complete turnover. I could visualize nothing but that marvelous exhibit of treated cases. Not one individual in the room had complimented the essayist. They were all ripping him to pieces for extracting teeth. Finally, I obtained the floor and complimented and defended him to the best of my ability. When I sat down, I, too, took a tongue-lashing that compared very favorably with the one Charlie had just received. Subsequently, I took his course, and practiced, taught and published his techniques in my textbook.

Tweed's many contributions to the specialty established a benchmark in orthodontic thought and treatment. Most notable among his many contributions were the following:

1. He emphasized the four objectives of orthodontic treatment—aesthetics, health, function, and stability—with emphasis and concern for balance and harmony of the lower face.
2. He developed the concept of positioning teeth over basal bone with emphasis on the mandibular incisors.[7]
3. He made the extraction of teeth for orthodontic correction acceptable.[8]
4. He enhanced the clinical application of cephalometrics.
5. He developed the diagnostic facial triangle[9] to make cephalometrics a diagnostic tool and a guide in treatment and in the evaluation of treatment results (Figure 15-5).
6. He developed a concept of orderly treatment procedures and introduced anchorage preparation as a major step in treatment.[10,11]
7. He developed a fundamentally sound and consistent preorthodontic guidance program that popularizied serial extraction of primary and, later, permanent teeth.

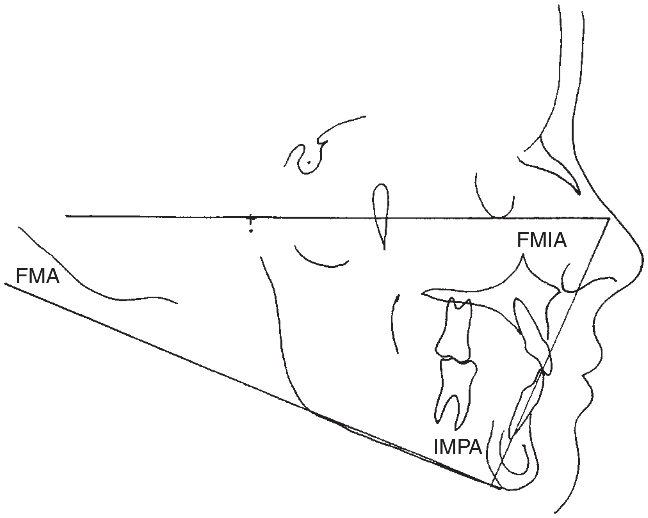


FIGURE 15-5 Tweed's diagnostic facial triangle. *FMA,* Frankfort mandibular plane angle; *FMIA,* Frankfort mandibular incisor axis angle; *IMPA,* lower incisor mandibular plane angle.

In addition to his many clinical contributions to the specialty, Tweed gave guidance, inspiration, and leadership to more orthodontists in the world than anyone else of his time. Because of Charles Tweed's skill and determination, the edgewise appliance became universally popular, and the practice of clinical orthodontics became a health service requested by the public.

Angle gave orthodontics the edgewise bracket, but Tweed gave the specialty the appliance. Tweed was considered the premier edgewise orthodontist of his day. Many who admired his results wished to learn his techniques. The orthodontic world journeyed to Tucson, Arizona, to take Tweed's course and learn his method of treatment with the edgewise appliance. The Tweed Philosophy was born.

Charles Tweed, one of orthodontics' most brilliant innovators, kept his promise to his mentor, Edward Hartley Angle. He devoted 42 years of his life, from 1928 until his death on January 11, 1970, to the advancement of the edgewise appliance.

LEVERN MERRIFIELD

In 1960 Tweed selected one of his most outstanding students, Levern Merrifield, from Ponca City, Oklahoma, to continue his work on the edgewise appliance. Tweed asked Merrifield to join him and be the codirector of his course (Figure 15-6). Merrifield took Tweed's course in 1953 and became a member of Tweed's staff in 1955. He became the course director at the time of Tweed's death in 1970. Merrifield devoted the remaining 45 years of his life to the study of orthodontic diagnosis and the use of the edgewise appliance. Merrifield's contributions have been disseminated and popularized. They include the following:

FIGURE 15-6 Levern Merrifield.

Diagnostic Concepts

1. The fundamental concept of dimensions of the dentition[11]
2. Dimensions of the lower face[12]
3. Total space analysis[13]
4. Guidelines for space management decisions to achieve the following:
   a. Maximum orthodontic correction
   b. Define areas of skeletal, facial, and dental disharmony[14]

Treatment Concepts

5. Directional force control during treatment[15]
6. Sequential tooth movement
7. Sequential mandibular anchorage preparation[16]
8. The organization of treatment into four orderly steps that have specific objectives

Merrifield's innovations in diagnosis and treatment planning and his experience with the edgewise appliance have augmented Tweed's contributions and concepts to give the modern orthodontist a more accurate, reliable, precise, efficient, and practical protocol of diagnosis, treatment planning and treatment. Adherence to this protocol allows the clinician to do the following:

a. Define objectives for the face, the dentition, and the skeletal pattern
b. Properly diagnose the malocclusion and treatment plan the maloccusion correction
c. Use the edgewise appliance to reach predetermined objectives efficiently

DIMENSIONS OF THE DENTITION

The clinical practice of orthodontics has always been based on the various dimensions of the dentition: height, width, and length (vertical, transverse, and sagittal). These dimensions allow the teeth to be moved in six directions: mesially, distally, facially, lingually, intrusively, and extrusively. All of these movements, which are accomplished routinely with orthodontic appliances, are limited and restricted by the physical environment of bone, muscle, and soft tissue, all of which exert an influence on the teeth and jaws.

Since the beginning of the orthodontic specialty, an effort has been made to determine the extreme limits of this environment. Each engineering change in appliance fabrication appears to bring about a new challenge to the physical limitations of the dentition's environment. Dimensions of the dentition include four basic premises, *provided that the musculature is normal:*

Premise 1: An anterior limit exists. The teeth must not be placed forward, off basal bone. If the teeth are too far forward, all the objectives of treatment are compromised.

Premise 2: A posterior limit exists. Teeth can be positioned and/or impacted into the area behind the mandibular first molar in the mandibular arch, even as they can be moved too far forward off basal bone.

Premise 3: A lateral limit exists. If the teeth are moved buccally into the masseter and buccinator muscles, relapse is likely to result over the long term.

Premise 4: A vertical limit exists. Vertical expansion is disastrous to facial balance and harmony in the sagittal plane, except in deep-bite cases.

In summary, orthodontists must recognize the limitations of the dental environment and design treatment to conform to these dimensions when normal muscle balance exists.

DIFFERENTIAL DIAGNOSIS

Merrifield, in his effort to establish a sound diagnostic basis for directional force treatment with multibanded mechanotherapy, introduced diagnostic analyses that allow clinicians to determine (1) whether and when extractions are necessary and (2) if extractions are indicated, which teeth should be removed. His work enabled the clinician to arrive at a differential diagnosis[17,18] instead of treating all extraction problems by the removal of four first premolars, as did Dr. Tweed. Merrifield's diagnostic philosophy can be outlined as follows:

1. Recognize and treat within the dimensions of the dentition. This means nonexpansion of malocclusions when normal muscular balance exists.

2. Recognize the dimensions of the lower face and treat for maximum facial harmony and balance.
3. Recognize and understand the skeletal pattern. Diagnose and treat in harmony with normal growth and developmental patterns and optimize the less than normal pattern. After the major areas of disharmony are identified, all necessary and practical means should be expended to correct the problem.

Facial Disharmony

A study of the face and its balance or lack of balance must be the first concern during a differential diagnosis. The clinician must have an intuitive concept of a balanced face. Essentially three factors influence facial balance or lack thereof: (1) the positions of the teeth, (2) the skeletal pattern, and (3) the soft tissue thickness.

Facial balance is influenced by protrusion and crowding of the teeth. Protruded teeth cause facial imbalance. The lips are supported by the maxillary incisor teeth. The upper lip rests on the upper two thirds of the labial surface of the maxillary incisors, and the lower lip is supported by the lower one third of the labial surface of the maxillary incisors; thus lip protrusion is a reflection of the degree of maxillary incisor protrusion. Maxillary incisor position is related directly, of course, to the position of the mandibular incisors.

Facial disharmonies can often be the result of abnormal skeletal relationships. The clinician must understand the skeletal pattern and have the ability to compensate for abnormal skeletal relationships by changing the positions of the teeth.[19] The Frankfort mandibular plane angle (FMA) is a skeletal angular value that is crucial in differential diagnosis. Dental compensation for a patient with a high FMA requires additional uprighting of mandibular incisors. Lower facial balance for the patient with a high FMA can be improved dramatically by using this knowledge.

Conversely, dental compensation for a patient with a low FMA requires less mandibular incisor uprighting. Decisions regarding tooth position objectives must be made after a thorough study of the skeletal pattern.

Facial disharmonies that are not the result of skeletal or dental distortion are generally the result of poor soft tissue distribution.[20,21] Poor soft tissue distribution needs to be identified during differential diagnosis so that dental compensations can be planned. The millimetric measurements of total chin thickness and upper lip thickness are essential components in any study of facial balance. Upper lip thickness is measured from the greatest curvature of the labial surface of the maxillary central incisor to the vermilion border of the upper lip (Figure 15-7). Total chin thickness is measured horizontally from the NB (Nasion-pt B) line extended to soft tissue pogonion. Total chin thickness should equal upper lip thickness. If total chin thickness is less than upper lip thickness, the anterior teeth must be positioned more upright to facilitate a more balanced facial profile because lip retraction follows tooth retraction.

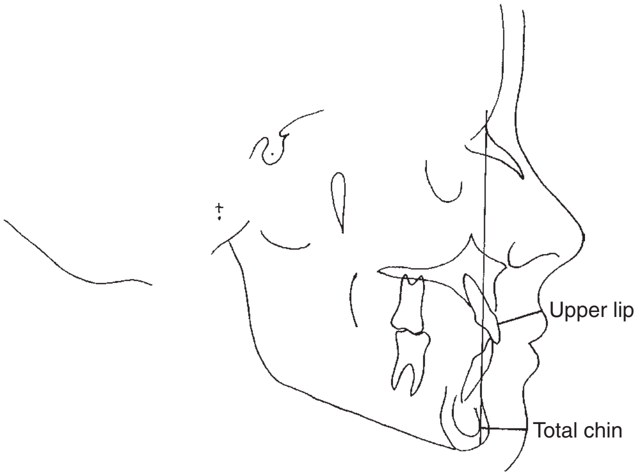


FIGURE 15-7 Upper lip equals total chin. Upper lip thickness should equal total chin thickness in the balanced face.

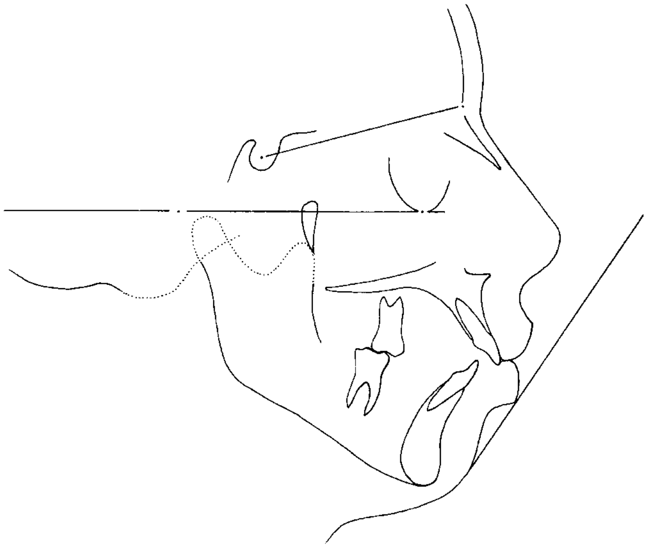


FIGURE 15-8 Profile line drawn on a protrusive face.

Careful consideration of the positions of the teeth, the skeletal pattern, and the soft tissue overlay will give crucial information about the face and enable the clinician to determine whether dental compensations will improve facial balance. Before initiating tooth movement, the clinician must clearly understand its impact on the overlying soft tissue.[22]

The profile line and its relationship to facial structures and to the Frankfort plane can be used to give the orthodontic practitioner an idea of lip procumbency. If the profile line lies outside the nose, a protrusion exists (Figure 15-8). When facial balance is present, the ideal relationship of profile line is to be tangent to the chin and the vermilion border of both lips and lie in the anterior one third of the nose (Figure 15-9). For centuries, the premise has been that this type of relationship of the profile line to the lips, chin, and nose reflects a pleasing and balanced appearance.

Similarly, on frontal view the face should be balanced. The vermilion border of the lower lip should bisect the distance between the bottom of the chin and the ala of the nose. The vermilion border of the upper lip also should bisect the distance from the vermilion border of the lower lip to the ala of the nose. These relationships are universally accepted orthodontic standards for facial balance and harmony.

Several cephalometric angles quantify facial balance. Two that have been found to be useful are the Z angle and the Frankfort mandibular incisor axis angle (FMIA) (Figure 15-10).

Z Angle. The chin/lip soft tissue profile line relationship to the Frankfort horizontal plane quantifies facial balance (see Figure 15-10). The normal range is 70 to 80 degrees.[12] The ideal value is 75 to 78 degrees, depending on age and gender. This angle was developed to define facial aesthetics further and is an adjunct to the FMIA. The Z angle is more indicative of the soft tissue profile than the FMIA and is responsive to maxillary incisor position. Maxillary incisor retraction of 4 mm allows 4 mm of lower lip retraction and about 3 mm of upper lip response. Horizontal mandibular repositioning also affects this value. Vertical facial height increase, either anterior and/or posterior, can influence the Z angle.

The Z angle quantifies the combined abnormalities in the values of the FMA, FMIA, and soft tissue thickness because all have a direct bearing on facial balance. The Z angle gives immediate guidance relative to anterior tooth repositioning. If the patient has a normal FMA of 25 degrees, a normal FMIA of 68 degrees, and good soft tissue overlay distribution, the Z angle value should be about 78 degrees.

Frankfort Mandibular Incisor Angle. Tweed established a standard of 68 degrees for individuals with an FMA of 22 to 28 degrees. The standard should be 65 degrees if the FMA is 30 degrees or more, and the FMIA will increase if the FMA is lower. Tweed believed that this value was significant in establishing balance and harmony of the lower face (see Figure 15-10).

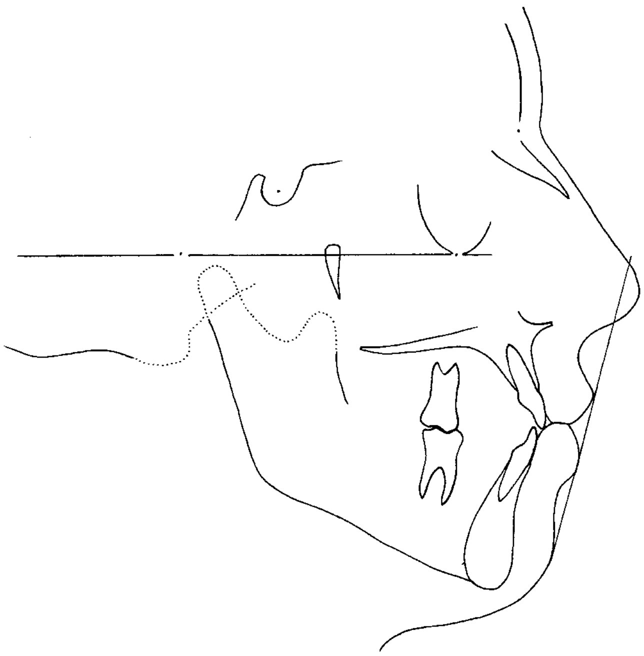


FIGURE 15-9 Profile line drawn on a facial profile that exhibits balance and harmony.

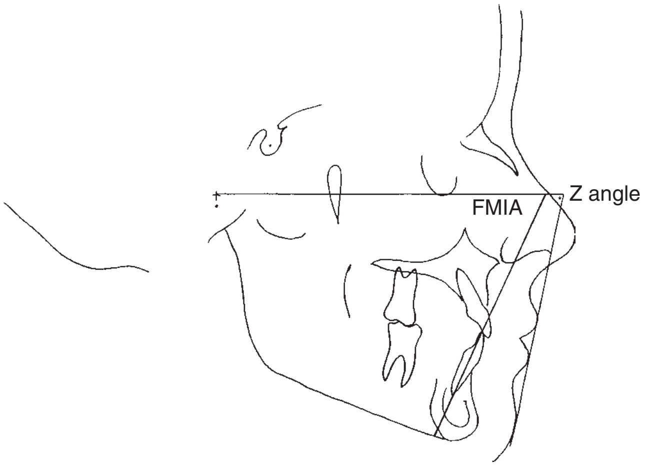


FIGURE 15-10 The Z angle and Frankfort mandibular incisor axis angle (FMIA). Tweed used the FMIA as an indicator of facial balance. Merrifield's Z angle quantifies balance of the lower face.

CASE REPORT 15-1

The records of this patient graphically illustrate the facial aesthetics "issue" in orthodontics. The pretreatment facial photographs (Figure 15-11) confirm an acceptable face. The casts (Figure 15-12) reflect mild crowding and a very moderate Class II occlusion. The pretreatment cephalometric tracing (Figure 15-13) shows skeletal and dental values that are "almost" normal.

The patient was treated for 18 months without regard for facial aesthetics (Figure 15-14). The progress cephalometric tracing (Figure 15-15) illustrates mandibular incisor flaring and loss of vertical dimension control. Compare the pretreatment photos with the "progress" photographs (Figure 15-16). Note the respective profile lines.

The patient's treatment plan was altered. Premolars were removed. The posttreatment facial photographs (Figure 15-17) show a balanced face. The posttreatment casts (Figure 15-18) illustrate a well interdigitated occlusion. The posttreatment cephalometric tracing (Figure 15-19) confirms mandibular incisors that are now in a proper position over basal bone. The pretreatment, "progress," and posttreatment facial photographs (Figure 15-20) illustrate the Tweed-Merrifield concept of treatment planning for maximum balance and harmony of the lower face.

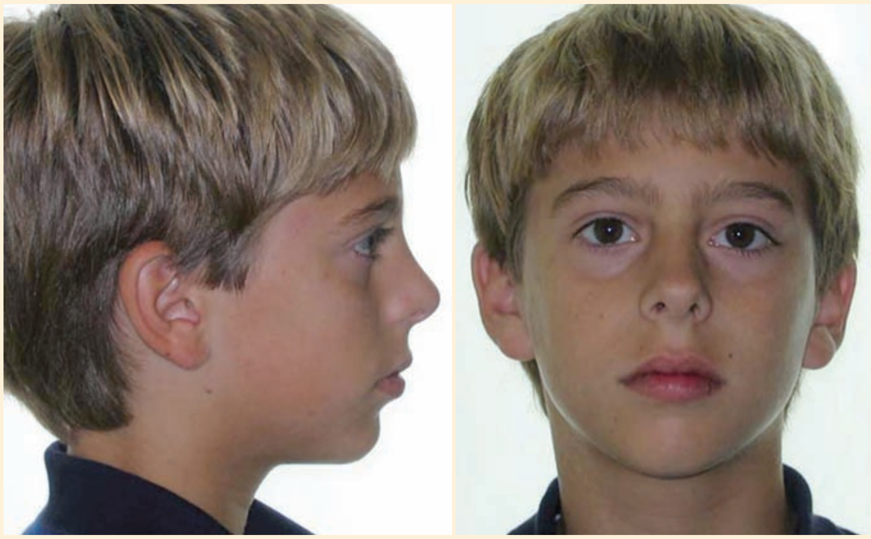


FIGURE 15-11 Pretreatment facial photographs.

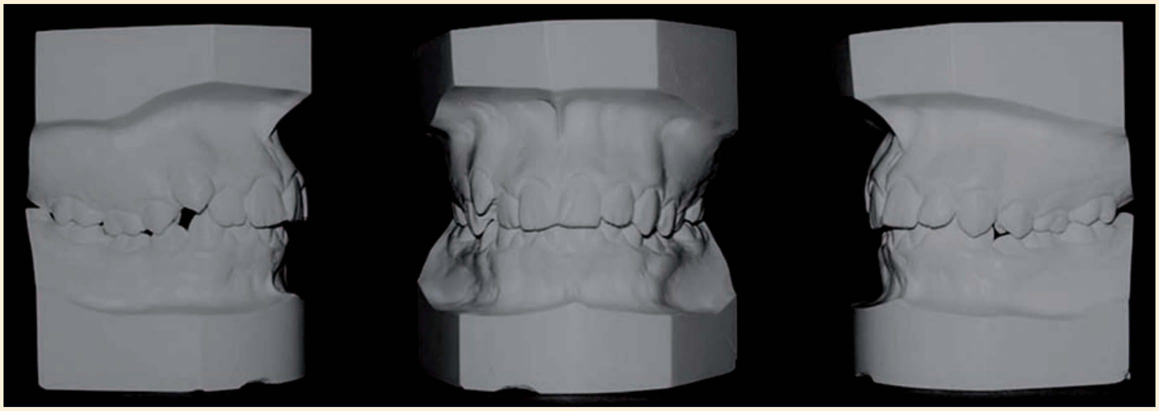
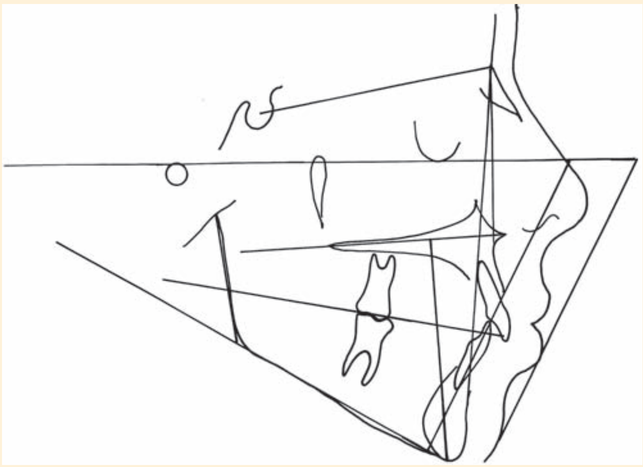


FIGURE 15-12 Pretreatment casts.

CASE REPORT 15-1



FMIA	64	OCC	9
FMA	30	Z	63
IMPA	86	UL	14mm
SNA	78	TC	12mm
SNB	75	PFH	41mm
ANB	3	AFH	67mm
AO-BO	0mm	INDEX	.61

FIGURE 15-13 Pretreatment cephalometric tracing.

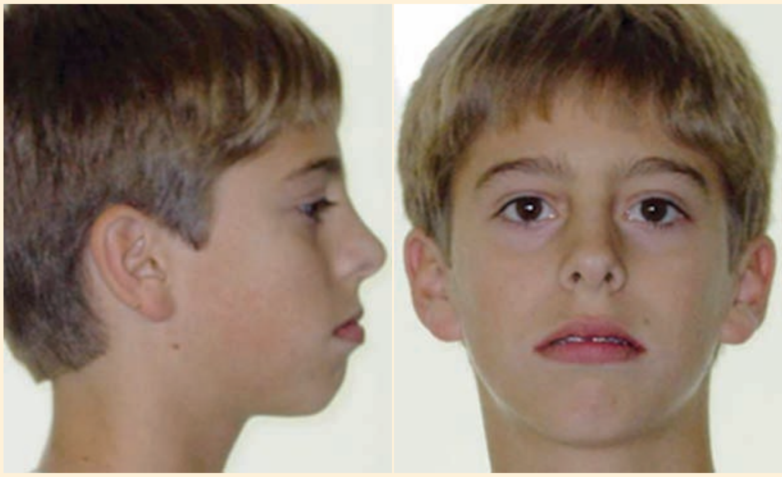
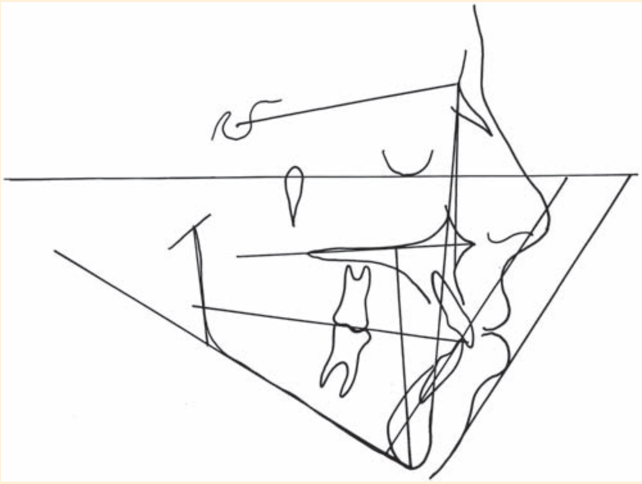


FIGURE 15-14 Facial photographs: 18 months of treatment.

Continued

CASE REPORT 15-1



FMIA	53	OCC	7
FMA	32	Z	56
IMPA	95	UL	14mm
SNA	78	TC	10mm
SNB	74	PFH	43mm
ANB	4	AFH	72mm
AO-BO	2mm	INDEX	.59

FIGURE 15-15 Progress cephalometric tracing.

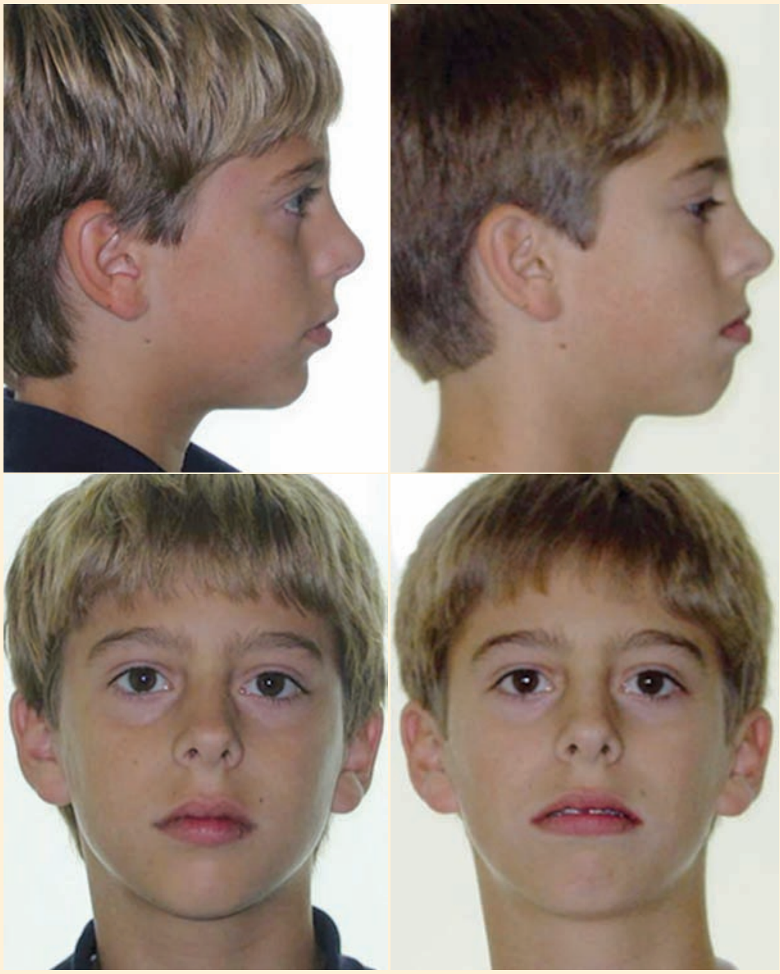


FIGURE 15-16 Pretreatment photographs with the "progress" photographs.

CASE REPORT 15-1

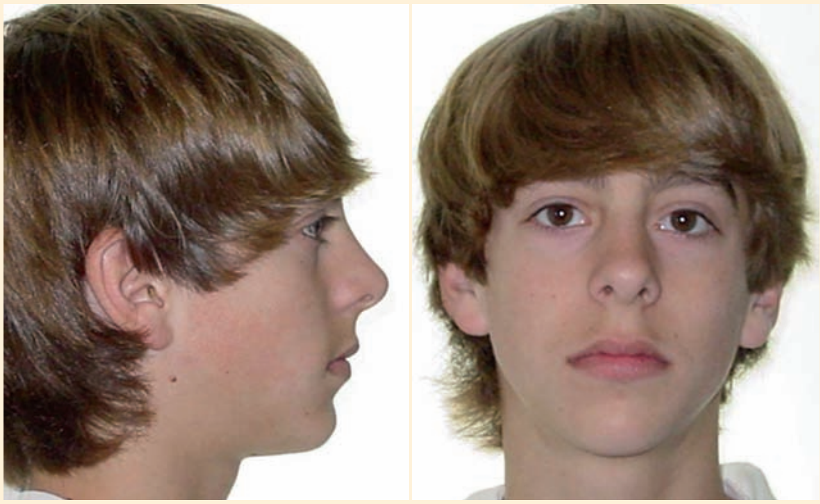


FIGURE 15-17 Posttreatment facial photographs.

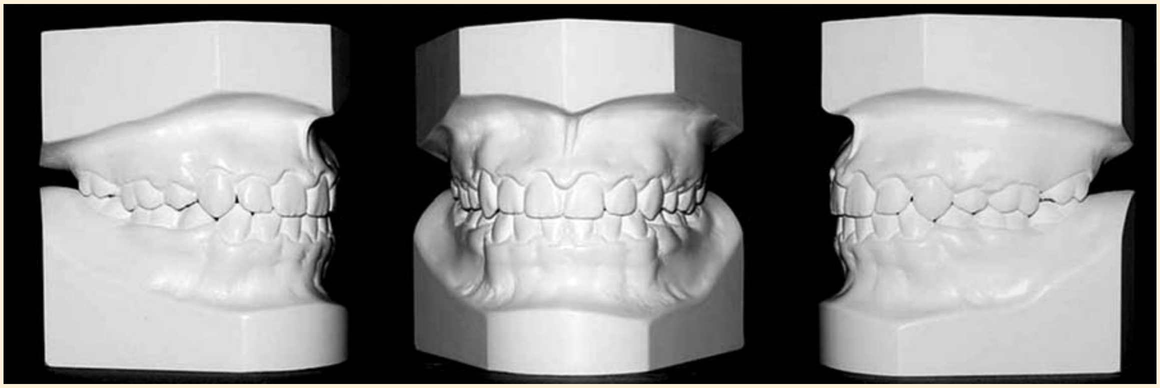


FIGURE 15-18 Posttreatment casts.

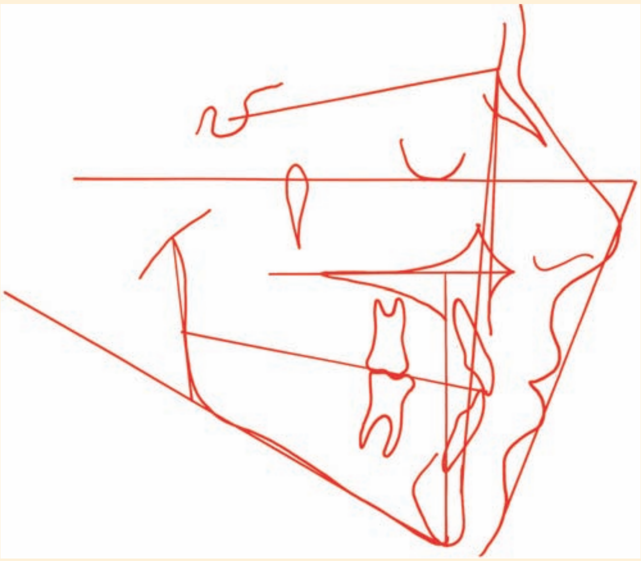


FIGURE 15-19 Posttreatment cephalometric tracing.

FMIA	66	OCC	9
FMA	30	Z	71
IMPA	84	UL	17mm
SNA	78	TC	12mm
SNB	76	PFH	47mm
ANB	2	AFH	74mm
AO-BO	−1mm	INDEX	.63

Continued

CASE REPORT 15-1

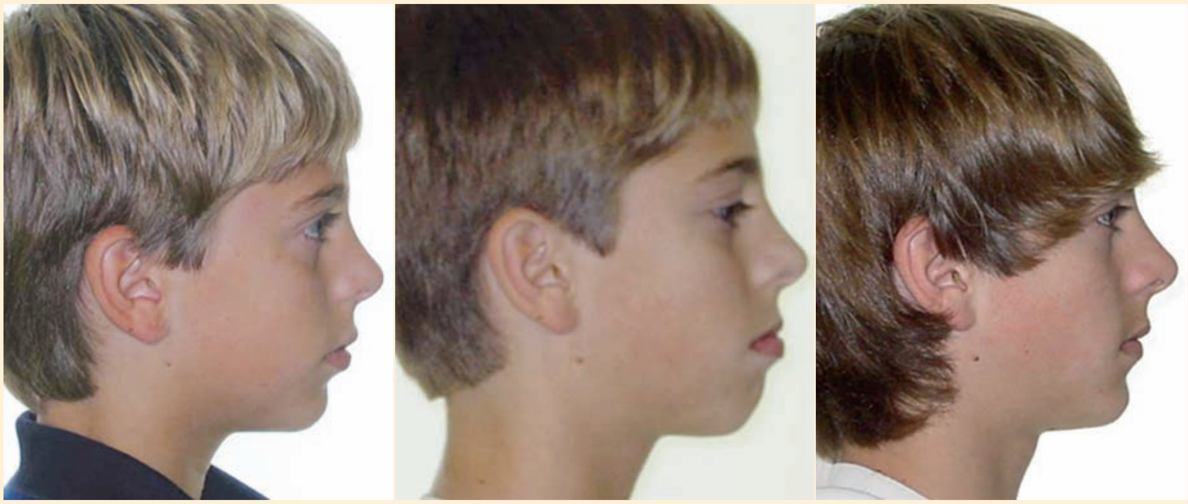


FIGURE 15-20 Pretreatment, "progress," and posttreatment facial photographs.

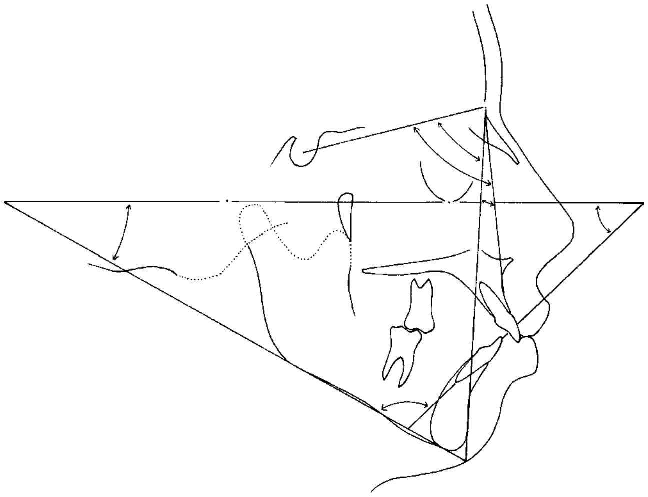


FIGURE 15-21 Cephalometric tracing with all values and planes.

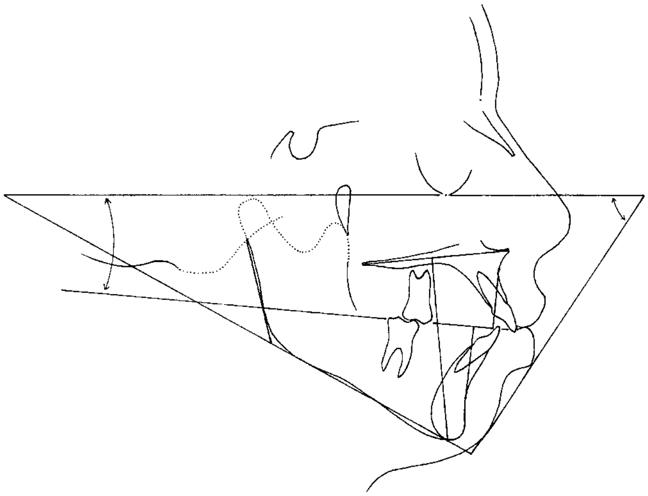


FIGURE 15-22 Cephalometric tracing with all values and planes.

Cranial Disharmony

An analytic observation of the skeletal pattern is an integral part of any diagnosis. A careful cranial analysis must include an understanding of the following information, which can be gleaned from a cephalogram (Figures 15-21 and 15-22).

Skeletal Analysis Values

Frankfort Mandibular Plane Angle (FMA). The FMA is probably the most significant value for skeletal analysis because it defines the direction of lower facial growth in the horizontal and vertical dimensions. The standard or normal range of 22 to 28 degrees for this value reflects a skeletal pattern with normal growth direction. An FMA greater than the normal range indicates excessive vertical growth direction, and an FMA less than the normal range indicates deficient vertical growth.

Incisor Mandibular Plane Angle (IMPA). IMPA defines the axial inclination of the mandibular incisors in relation to the mandibular plane. The IMPA is a good guide to use in maintaining or positioning these teeth in their relationship to basal bone. The standard of 88 degrees indicates an upright mandibular incisor position that with a normal FMA will ensure optimal balance and harmony of the lower face. If the FMA is above normal, the orthodontist must dentally compensate with more uprighting of the mandibular incisors. If the FMA is below the normal range, compensation can be made by leaving the mandibular incisors in their pretreatment position or, in rare instances, by positioning them more to the labial. Labial inclination of the mandibular incisors is generally limited to their original inclination if the patient has normal muscular balance.

Sella-Nasion-Subspinale Angle (SNA). The SNA angle indicates the relative horizontal position of the maxilla to cranial base. The range at the termination of growth is 80 to 84 degrees for a white population sample.

Sella-Nasion-Supramentale Angle (SNB). The SNB angle expresses the horizontal relationship of the mandible to the cranial base. A range of 78 to 82 degrees indicates a normal horizontal mandibular position. If the value is less than 74 degrees and a large maxillomandibular discrepancy exists, orthognathic surgery should be considered as an adjunct to orthodontic treatment. The same concern should be accorded to a value of more than 84 degrees.

Subspinale-Nasion-Supramentale Angle (ANB). The normal range for the ANB angle is 1 to 5 degrees. This value expresses a very "treatable" horizontal relationship of the maxilla to the mandible. Class II malocclusions become proportionally more difficult with higher ANB angles. A patient with an ANB greater than 10 degrees will usually require surgery as an adjunct to proper treatment. The negative ANB angle is even more indicative of facial disproportion in the horizontal dimension. An ANB angle of −3 degrees or more, when the mandible is in its centric relation, indicates a possibility for the need of surgical assistance in Class III malocclusion correction.

AO-BO. The AO-BO relationship quantifies the horizontal relationship of the maxilla to the mandible and is perhaps more sensitive to malrelationships than the ANB angle because it is measured on the occlusal plane. Orthodontic treatment becomes more difficult when the AO-BO is greater than the normal range of 0 to 4 mm. The AO-BO changes in direct proportion to the occlusal plane angle.

Occlusal Plane. The occlusal plane angle expresses a dentoskeletal relationship of the occlusal plane to the Frankfort horizontal plane. A range of 8 to 12 degrees is normal with variations of about 2 degrees between males and females. The angle for the female averages about 9 degrees and for the male about 11 degrees. Values greater or less than the normal range indicate more difficulty in treatment. During most orthodontic malocclusion corrections, the original value should be maintained or decreased. An increase in the occlusal plane angle during treatment indicates a loss of vertical control. An increase is usually unstable because the occlusal plane is determined by muscular balance, primarily the muscles of mastication. The occlusal plane angle frequently returns to its pretreatment value when it is increased. The result is a detrimental relapse of the "corrected" interdental relationship.

Posterior Facial Height (PFH). PFH is a linear millimetric measurement of ramus height from articulare to the mandibular plane tangent to the posterior border of the ramus. The value is related to facial form, vertically and horizontally. The relationship of PFH to anterior facial height determines the FMA and lower facial proportion. In the growing child with a Class II malocclusion, ramal growth change and its relationship to anterior facial height in proportion and in volume are crucial.

Anterior Facial Height (AFH). The AFH is a linear millimetric measurement of the vertical distance between the palatal plane and menton. The line is drawn perpendicular to the palatal plane. A value of about 65 mm for a 12-year-old individual indicates a normal anterior facial height. This vertical value must be monitored carefully if it is 5 mm more or less than normal. During Class II malocclusion correction, limiting an increase in AFH is essential and can be accomplished by controlling maxillary and mandibular molar extrusion in conjuction with an anterior "high-pull" force on the maxilla.

Facial Height Index. André Horn[23] studied the relationship of AFH to PFH. After developing the facial height index, he found that normal PFH is 0.69, or 69%, of AFH. The normal range of PFH to AFH is 0.65 to 0.75. If the value is less than or greater than this range, the malocclusion is more complex and the orthodontist will encounter difficulty in correction. An index of 0.80 is severe and indicates a "low FMA" malocclusion caused by too much posterior ramal growth or too little anterior growth. As the index approaches 0.60, the skeletal pattern demonstrates too little posterior height or too much anterior height.

Facial Height Change Ratio. The facial height change ratio is valuable in the evaluation of treatment interval changes. A ratio of 2 times as much PFH increase as AFH increase during treatment is ideal for the correction of Class II, Division 1 and dentoalveolar protrusion malocclusions. However, even more important is the volume of change. For example, a 6-mm PFH increase with a 3-mm AFH increase is much more beneficial than a 2-mm PFH increase coupled with a 1-mm AFH increase even though both values reflect a 2 : 1 ratio.

Radziminski,[24] Gebeck and Merrifield,[25,26] Issacson,[27] Pearson,[28,29] and Schudy[30] have described the important relationship between vertical dimension control and successful treatment of Class II malocclusions. After an evaluation of successfully and unsuccessfully treated Class II malocclusions, Merrifield and Gebeck[26,31,32] concluded that successfully treated patients exhibited favorable mandibular changes. These changes occurred in part because AFH was controlled while PFH increased. Unsuccessful treatment results were more likely to occur in patients in whom an increase was observed in AFH but not in PFH. Merrifield and Gebeck reported a 2 : 1 ratio of increase in PFH to AFH in their sample of successfully treated Class II malocclusions; that is, PFH increased on the average twice as much as AFH.

Craniofacial Analysis. For a period of about 15 years, until his untimely death in June 1993, Jim Gramling of Jonesboro, Arkansas, was the research director for the Charles H. Tweed Foundation. During those years, Gramling compiled a large sample of successfully and unsuccessfully treated Class II malocclusions.[33,34]

From the background of evidence gathered from these studies, Gramling formulated a probability index[35,36] for three specific purposes:

1. To augment diagnostic procedures
2. To guide treatment procedures
3. To predict possible treatment success or failure

Gramling statistically established a difficulty factor and assigned a specific number of points to each variable (Table 15-1).

In 1989, Gramling studied a different sample of 40 successful and 40 unsuccessful Class II malocclusion corrections.[36] After this study, he revised only one of the five premises of the probability index. He changed the successful FMA range of 18 to 35 degrees to 22 to 28 degrees (Table 15-2).

Using information from the previously described clinical research, the craniofacial analysis (Table 15-3), an integral component of the differential diagnostic analysis system, was developed. Each of the six cephalometric values used has been determined to have significant merit. The interrelationship of each of the values has been weighted statistically in relationship to its individual significance and mathematical value. In determining the difficulty of correction, the areas were weighted, taking into consideration the necessary diagnostic decisions and the complexity and importance of treatment management.

TABLE 15-1 The Probability Index Variables with the Statistically Computed Difficulty Factors

Cephalometric Angle	Variation
FMA	5 points
ANB	15 points
FMIA	2 points
Occlusal plane	3 points
SNB	5 points

Note: This was Gramling's initial attempt at a probability index.

The FMA, the AFH/PFH ratio, and the occlusal plane to Frankfort angle are significant when used as a group. These values make up the vertical component of the craniofacial analysis. The vertical skeletal pattern can be a problem of excessive AFH in the presence of a decreased PFH, or conversely, a problem of excessive PFH and a decreased AFH. If facial height, anterior or posterior, is out of proper proportion, correction of the malocclusion is more difficult, and one must take great care with treatment procedures so that the vertical disharmonies do not significantly worsen.

The horizontal skeletal component of the craniofacial analysis is composed of the SNB and the ANB. A high ANB caused by a low SNB makes the horizontal skeletal disharmony much more difficult to manage than if the high ANB is caused by an excessive SNA. The low SNB requires a treatment compromise or, if a more ideal result is desired, orthognathic surgery.

The previously described Z angle value is the only nonskeletal measurement in the craniofacial analysis. The Z angle was included because it is a facial indicator of craniofacial imbalance.

Dental Disharmony

Total Dentition Space Analysis. Along with a consideration of the face and the skeletal pattern, the

TABLE 15-2 The Probability Index after the Pretreatment Range for FMA Was Adjusted Downward to 22 to 28 Degrees

	Point Value	Cephalometric Value	Probability Index
FMA 22 to 28 degrees	5	—	—
ANB 6 degrees or less	15	—	—
FMIA 60 degrees or more	2	—	—
Occlusal plane 7 degrees or less	3	—	—
SNB 80 degrees or more	5	—	—
Total			—

TABLE 15-3 Craniofacial Analysis

Normal Range	Cephalometric Value	Difficulty Factor	Difficulty
FMA 22 to 28 degrees	—	5	—
ANB 1 to 5 degrees	—	15	—
Z angle 70 to 80 degrees	—	2	—
Occlusal plane 8 to 12 degrees	—	3	—
SNB 78 to 82 degrees	—	5	—
FHI (PFH-AFH) 0.65 to 0.75	—	3	—
Craniofacial difficulty total			—

TABLE 15-4 Total Space Analysis

Area	Value	Difficulty Factor	Difficulty
Anterior			
Tooth arch discrepancy	—	1.5	—
Head film discrepancy	—	1.0	—
Total	—		—
Midarch			
Total arch discrepancy	—		—
Curve of Spee	—		—
Total	—		—
Occlusal disharmony (Class II or Class III)	—	2	—
Posterior			
Tooth arch discrepancy	—		
Expected increase (–)	—		
Total	—	0.5	—
Space analysis total	—	Space analysis difficulty total	—

orthodontist must consider the dentition (Table 15-4). Total space analysis as described by Merrifield[13] is divided into three parts: anterior, midarch, and posterior. This division is made for two reasons: (1) simplicity in identifying the area of space deficit or space surplus and (2) accuracy in differential diagnosis.

Anterior Space Analysis. Anterior space analysis includes the measurement in millimeters of the space available in the mandibular arch from canine to canine and a measurement of the mesiodistal dimension of each of the six anterior teeth. The difference is referred to as a surplus or deficit. Tweed's diagnostic facial triangle and the cephalometic descrepancy calculated from it are also used to further analyze this area. Cephalometric discrepancy is defined as the amount of space required to upright the mandibular incisors for optimum facial balance. This value is added to the anterior space measurement.

The sum of the anterior tooth arch surplus or deficit and the cephalometric discrepancy is referred to as the anterior discrepancy. Each of the values in the anterior discrepancy calculation has been given a difficulty factor so that an anterior space analysis difficulty value can be calculated.

Midarch Space Analysis. The midarch area includes the mandibular first molars and the first and second premolars. The midarch is an important area of the dentition. Careful analysis of this area may show mesially inclined first molars, rotations, spaces, a deep curve of Spee, crossbites, missing teeth, habit abnormality, blocked-out teeth, tooth size discrepancies, and occlusal disharmonies. Careful measurement of the space from the distal of the canine to the distal of the first molar should be recorded as available midarch space. An equally accurate measurement of the mesiodistal width of the first premolar, the second premolar, and the first molar must also be recorded. To this value is added the space required to level the curve of Spee.[37] From these measurements, the orthodontist can determine the space deficit or surplus in this area.

Occlusal disharmony, a Class II or III buccal segment relationship, though not a part of the actual midarch space analysis, must be measured because an occlusal disharmony adds a great deal to the difficulty of correction of any malocclusion and requires careful treatment strategy and space management.

Occlusal disharmony is measured by articulating the casts and by using the maxillary first premolar cusp and its relationship to the mandibular first premolar/second premolar embrasure as a reference. Measure mesially or distally from the maxillary first premolar buccal cusp to the embrasure between the mandibular first and second premolars. This measurement is made on both sides and is then averaged to determine the occlusal disharmony. The difficulty factor for occlusal disharmony is "2," so the averaged disharmony is doubled and added to the midarch difficulty because it has to be corrected by moving teeth that are in the midarch area of the dentition.

Posterior Space Analysis. The posterior dentition area is of great importance. The dentition has a posterior limit. Regardless of age, this posterior limit appears to be the anterior border of the ramus. The required space in the posterior space analysis is the mesiodistal width of the second molars and the third molars in the mandibular arch. The available space is more difficult to ascertain on the immature patient. It is a linear measurement in millimeters of the space distal to the mandibular first molars. The measurement is made from the distal of the mandibular first molar to the anterior border of the ramus along the occlusal plane. The posterior limit is recognized as being 2 to 3 mm distal to the anterior border of the ramus because of the lingual shelf that exists to accommodate the mandibular molars. However, teeth on the lingual shelf are not generally in good functional occlusion.

An estimate of posterior arch length increase based on age and gender is added to this value. Certain unpredictable variables must be considered in estimating the increase in posterior available space. These variables are the following:

1. Rate of mesioocclusal migration of the mandibular first molar
2. Rate of resorption of the anterior border of the ramus
3. Time of cessation of molar migration
4. Time of cessation of ramus resorption
5. Gender
6. Age

A review of the literature[38–40] reveals that the consensus from researchers suggests that 3 mm of increase per year occurs in the posterior dentition area until age 14 for girls and age 16 for boys. This is an increase of 1.5 mm per year on each side of the arch after the complete eruption of the first molars. In the mature patient (girls beyond 15 years and boys beyond 16 years), a measurement from the distal of the first molar to the anterior border of the ramus at the occlusal plane is a valuable determination of the space available in the posterior area. This measurement is important in diagnosis and treatment because it gives the clinician the ability to know whether a surplus or deficit of space exists in this area.

To create a posterior discrepancy while making adjustments in either the midarch or anterior area is not prudent. Equally imprudent is to not use a posterior space surplus to help alleviate midarch and anterior deficits. The most easily recognizable symptom of a posterior space deficit in the young patient is the late eruption of the second molars. If space is not available for these teeth by the age of their normal eruption, it should be obvious that a posterior space problem exists. The posterior space analysis surplus or deficit has been given a low difficulty factor of 0.5 because a posterior space deficit can be easily resolved with third molar removal.

Differential Diagnostic Analysis System

The two diagnostic tools that have been described, the craniofacial analysis and the total dentition space analysis, used together, make up the differential diagnostic analysis system (Table 15-5). Use of this diagnostic methodology will significantly improve the clinician's ability to diagnose, plan, and execute treatment. The sum of the craniofacial difficulty and the total dentition space analysis difficulty is called total difficulty. This value will give the clinician a quantitative method of evaluating

TABLE 15-5 Differential Diagnostic Analysis System

Craniofacial Analysis **Normal Range**	**Cephalometric Value**	**Difficulty Factor**	**Difficulty**
FMA 22 to 28 degrees	—	5	—
ANB 1 to 5 degrees	—	15	—
Z angle 70 to 80 degrees	—	2	—
Occlusal plane 8 to 12 degrees	—	3	—
SNB 78 to 82 degrees	—	5	—
FHI (PFH-AFH) 0.65 to 0.75	—	3	—
Craniofacial difficulty total			—
Total Space Analysis	**Value**	**Difficulty Factor**	**Difficulty**
Anterior			
Tooth arch discrepancy	—	1.5	—
Head film discrepancy	—	1.0	—
Total	—		
Midarch	—		
Tooth arch discrepancy	—	1.0	—
Curve of Spee	—	1.0	—
Total	—		
Occlusal disharmony (Class II or Class III)	—	2.0	—
Posterior			
Tooth arch discrepancy	—		
Expected increase (–)	—		
Total	—	0.5	—
Space analysis total	—	Space analysis difficulty total	—
Craniofacial difficulty total	—		
Space analysis difficulty total	—		
Total difficulty	—		

the difficulty of correction for each malocclusion. The analysis identifies the specific areas of major disharmony (i.e., facial, skeletal, and dental) and gives guidance for treatment strategy.

Other factors such as habit evaluation, joint health, muscle balance, dental or skeletal malrelationships, and other cephalometric values must be duly noted, evaluated by the orthodontist, and factored into any diagnosis. The orthodontist must also evaluate the patient's motivation and desire for orthodontic correction. The range of values for the total difficulty that have been found to be most appropriate when malocclusion correction difficulty is studied are as follows: mild, 0 to 60; moderate, 60 to 120; and severe, more than 120.

TWEED-MERRIFIELD EDGEWISE APPLIANCE

Brackets and Tubes

An appliance is an instrument used to achieve orthodontic goals. As Angle stressed, an appliance must have certain characteristics: simplicity, efficiency, and comfort. An appliance must also be hygienic, aesthetic, and above all, have a wide range of versatility. The neutral 0.022 slot edgewise appliance consists of posterior bands and anterior mesh pads with single, double-width 0.022 brackets on the six anterior teeth; intermediate single-width brackets on premolar bands; twin brackets on first molar bands; and heavy edgewise 0.022 tubes with mesial hooks on second molar bands (Figure 15-23).

All bands have lingual cleats attached. Lingual cleats increase versatility and are especially necessary to correct and control rotations. Each of the brackets and tubes is placed at a right angle to the long axis of the tooth. The brackets are positioned precisely in relation to the incisal edges of the incisor teeth and the cusps of the remaining teeth. No tip, torque, or variations in thickness are present in the bracket. A slot size of 0.022 allows the clinician to use a multiplicity of archwire dimensions.

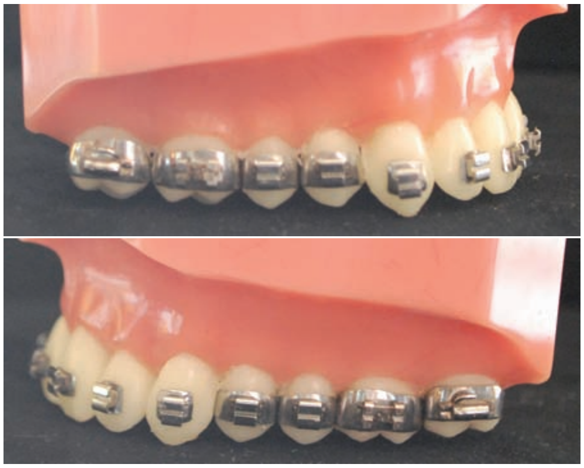


FIGURE 15-23 Tweed-Merrifield edgewise appliance. The appliance is composed of neutral 0.022-inch edgewise slots with double-width brackets on the six anterior teeth, intermediate single-width brackets on the premolar bands, twin brackets on the first molars, and 0.022-inch tubes with mesial hooks on the second molars.

Archwires

Resilient edgewise archwire is used with the Tweed-Merrifield 0.022-inch edgewise appliance. The dimensions (in inches) of the wire commonly used are 0.017 × 0.022, 0.018 × 0.025, 0.019 × 0.025, 0.020 × 0.025, and 0.0215 × 0.028. These wire dimensions give a great range of versatility with the 0.022 × 0.028 bracket slot and allow the sequential application of forces as needed for various treatment objectives. The objective is to enhance tooth movement and control with the proper edgewise archwire at the appropriate time.

First-, Second-, and Third-Order Bends and Their Interaction

Knowledge of the action, interaction, and reaction of teeth to bends in the archwire is crucial to the use of any orthodontic appliance. Such knowledge is fundamental and drastically affects clinical results.

First-Order Bends. The action and reaction of first-order bends affect expansion or contraction. These actions are monitored easily and are routinely used to move individual teeth. The interaction of the bends can affect the third-order position of the teeth if expansion forces are used.

Second-Order Bends. Second-order bends in the posterior segment of the mandibular archwire are antagonistic to the teeth in the anterior segment. Without excellent directional control and a careful application of these second-order forces in a sequential manner, vertical control of the anterior teeth will be lost.

Second-order bends in the posterior segment of the mandibular archwire also negatively affect the third-order position of the mandibular anterior teeth. Therefore, the mandibular anterior teeth generally require lingual crown torque in the archwire because posterior second order tipping bends apply labial crown torque force to the incisors. This fact must be given careful consideration in archwire fabrication and force application.

In the maxillary arch, second-order bends (an exaggerated curve of Spee) in the posterior segments is generally desirable or complementary to the teeth in the anterior segment. The reaction to the tipping forces intrudes the maxillary incisors and gives a lingual root torque effect to these teeth. This is generally positive or complementary to treatment objectives.

Third-Order Bends. Third-order bend reaction in the mandibular archwire is complementary to all the teeth if properly placed. The objective is to have some degree of lingual crown torque on all the mandibular teeth. The posterior and anterior segments work together in action, reaction, and interaction. The ideal third-order bends (lingual crown torque) in the mandibular archwire are as follows: incisors, 7 degrees; canines and first premolars, 12 degrees; and second premolars and molars, 20 degrees.

Conversely, third-order bends in the maxillary archwire are antagonistic. The anterior segment needs no torque (0 degrees) or slight lingual root torque, and the posterior segment needs lingual crown torque: canines and first premolars (7 degrees) and second premolars and molars (12 degrees). Application of active third-order force simultaneously in segments with opposite actions is not wise. In the maxillary arch, applying active third-order bends sequentially and in only one direction at any given time is prudent.

Auxiliaries

The auxiliaries routinely used with the Tweed-Merrifield edgewise force system are elastics and directionally oriented headgear, primarily the high-pull J-hook headgear and the straight-pull J-hook headgear. Patient compliance is imperative.

Variations of the Appliance

Many variations of the edgewise appliance have been introduced in the past 30 years. Most notable of the variations is the "straight wire" appliance introduced in 1972 by Larry Andrews.[1] The straight wire appliance incorporates first-, second-, and third-order bends into the bracket. The theory behind this approach is that these bends will not have to be placed in the archwire. Another variation is a decrease in slot size from 0.022 to 0.018 inch and even to 0.016 inch. Various orthodontic suppliers market numerous variations of the straight wire appliance with different tip and torque to suit the individual operator's desires. Other modifications have been extensively described by Burstone,[41] Lindquist,[42] and Roth.[43]

TREATMENT WITH THE TWEED-MERRIFIELD EDGEWISE APPLIANCE

Any treatment protocol must complement a diagnostic philosophy. Using Tweed's treatment concepts as a foundation, Merrifield developed force systems that simplify the use of the edgewise appliance. For example, Tweed used 12 sets of archwires during the treatment of each patient. Today, with the modern edgewise appliance, only four to five sets of archwires are used. Merrifield's sequential directional force technology[44–46] is simple, straightforward, and fundamentally sound. From the era of Tweed and into the era of Merrifield, the key to quality treatment with the edgewise appliance continues to be directionally controlled precision archwire manipulation. Essentially five concepts compose the treatment philosophy: (1) sequential appliance placement, (2) sequential and/or individual tooth movement, (3) sequential mandibular anchorage preparation, (4) directional forces including control of the vertical dimension to enhance mandibular response, and (5) proper timing of treatment.

Sequential Appliance Placement

The application of the appliance to the patient is important. In a first premolar extraction patient, the second molars and the second premolars are banded. Initially, the first molars are left unbanded. The central incisors, lateral incisors, and canines are bonded. Anterior teeth that are malaligned are not ligated to the archwire or are ligated passively. This method of sequential appliance placement is less traumatic to the patient and is easier and less time consuming for the orthodontist. The method allows much greater efficiency in the action of the archwire during the first months of treatment because it gives the posterior segment of the archwire much longer interbracket length. This length creates a power storage that accomplishes second molar movement more rapidly. Sequential appliance placement also gives the orthodontist the opportunity to insert a wire of larger dimension that is less subject to occlusal or bracket engagement distortion.

After the banded and bracketed teeth respond to the forces of the archwire and auxiliaries, the first molars are banded. The maxillary first molars are banded after one appointment. The mandibular first molars are banded after the second appointment.

Sequential Tooth Movement

Tooth movement is sequential. It is not the en masse movement that was introduced by Tweed. Individual teeth are moved rapidly and with precision because they are moved singly or in small units.

Sequential Mandibular Anchorage Preparation

Tweed attempted, with varying degrees of success, to prepare mandibular anchorage with Class III elastics. All the compensation bends were placed in the archwire at one time. Sequelae of this force system were often labially flared and intruded mandibular incisors. Sequential mandibular anchorage preparation, developed by Merrifield, is a system that allows mandibular anchorage to be prepared quickly and easily by tipping only two teeth at a time to their anchorage prepared position. This system uses high-pull headgear rather than Class III elastics for support.

Unlike the en masse anchorage of the Tweed era, movement is controlled, sequential, and precise. It is accomplished by using 10 teeth as "anchorage units" to tip two teeth and often is referred to as the Merrifield

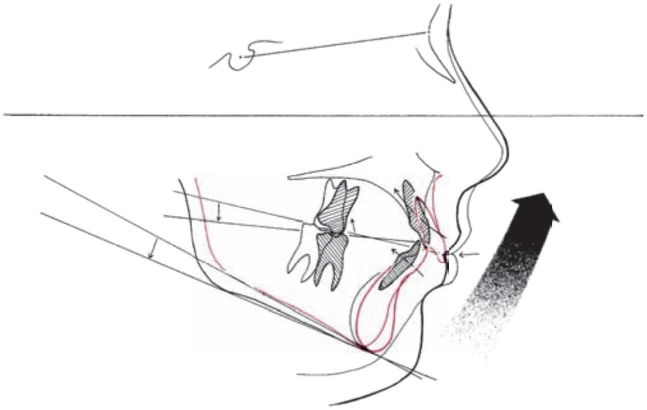


FIGURE 15-24 Upward and forward force system.

"10-2" system. In the initial step of treatment, denture preparation, the second molar is tipped to its desired anchorage prepared position. After space is closed, a compensating bend is placed mesial to the second molar to maintain its tip, and the mandibular first molar is tipped to an anchorage prepared position. After the first molar is tipped, a compensation bend is placed mesial to it to maintain its tip, and the second premolar is tipped distally to its anchorage prepared position.

Directional Force

The hallmark of modern Tweed-Merrifield edgewise treatment is the use of directional force systems to move the teeth. Directional forces can be defined as controlled forces that place the teeth in the most harmonious relationship with their environment.

To use a force system that controls the mandibular posterior teeth and the maxillary anterior teeth is crucial. The resultant vector of all forces should be upward and forward to enhance the opportunity for a favorable skeletal change, particularly during dentoalveolar protrusion Class II malocclusion correction (Figure 15-24). An upward and forward force system requires that the mandibular incisor be upright over basal bone so that the maxillary incisor can be moved properly (Figure 15-25). For the upward and forward force system to be a reality, vertical control is crucial. To control the vertical dimension, the clinician must control the mandibular plane, palatal plane, and occlusal plane. If point B drops down and back, the face becomes lengthened, the mandibular incisor is tipped forward off basal bone, and the maxillary incisor drops down and back instead of being moved to a proper functional and aesthetic position (Figure 15-26). The unfortunate result of this procedure is a patient with a lengthened face, a gummy smile, incompetent lips, and a more recessive chin.

Timing of Treatment

The timing of treatment is an integral part of the philosophy. Treatment should be initiated at the time when treatment objectives can be accomplished most readily. This may mean interceptive treatment in the mixed dentition, selected extractions in the mixed dentition, or waiting for permanent second molar eruption before initiating active treatment. Diagnostic discretion is the determinant.

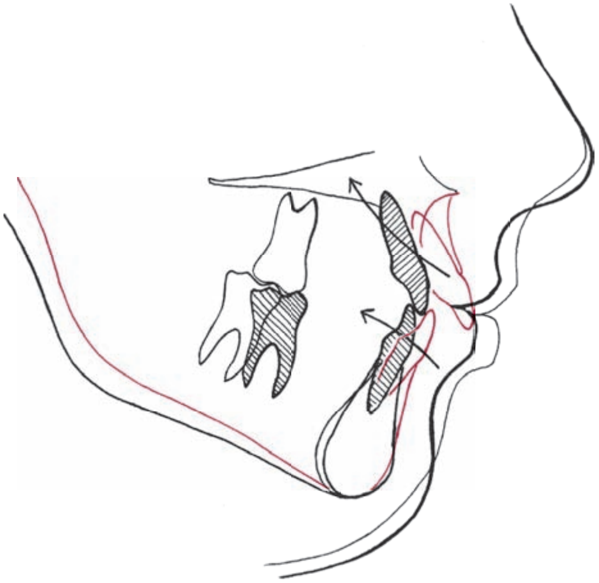


FIGURE 15-25 Upright mandibular incisor and maxillary incisor moved up and back.

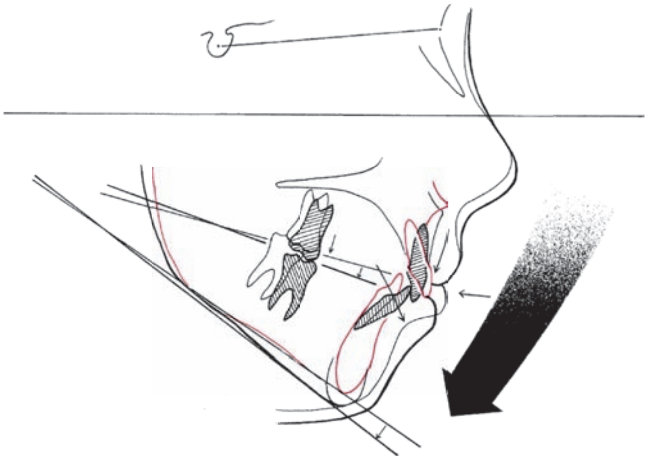


FIGURE 15-26 Downward and backward force system.

STEPS OF TREATMENT

Tweed-Merrifield edgewise directional force treatment can be organized into four distinct steps: denture preparation, denture correction, denture completion, and denture recovery. During each step of treatment, certain objectives must be attained.

Denture Preparation

Denture preparation prepares the malocclusion for correction. Objectives include the following:

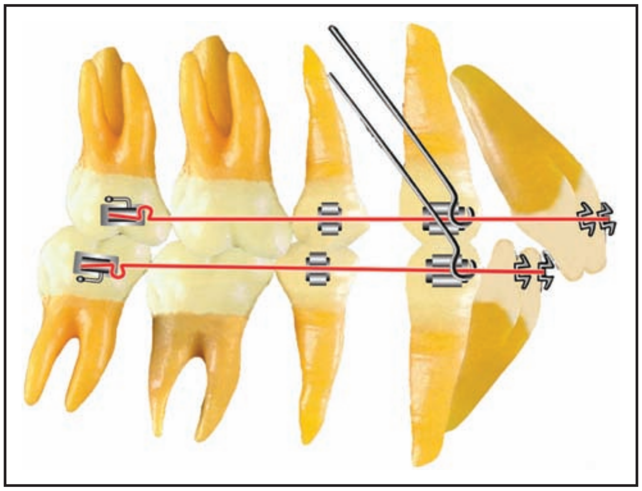


FIGURE 15-27 Denture preparation: initial archwires. Initial archwires consist of a 0.017- × 0.022-inch resilient maxillary archwire and a 0.018- × 0.025-inch resilient mandibular archwire.

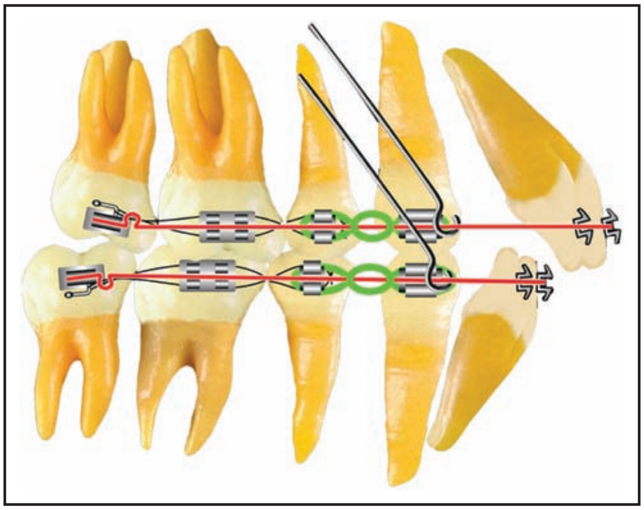


FIGURE 15-28 Denture preparation: canine retraction. The canines are retracted with a J-hook headgear during denture preparation.

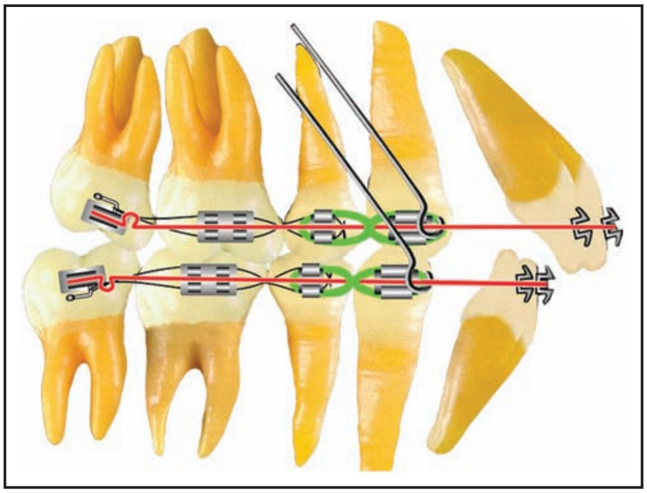


FIGURE 15-29 Denture preparation: terminal molar anchorage. At the end of denture preparation the mandibular terminal molar should be tipped to an anchorage-prepared position.

1. Leveling
2. Individual tooth movement and rotation correction
3. Retraction of maxillary and mandibular canines
4. Preparation of the terminal molars for stress resistance

The denture preparation step of treatment takes about 6 months. One mandibular archwire and one maxillary archwire are used to complete this step.

The teeth of the original malocclusion are sequentially banded and bonded (Figure 15-27). After the placement of the appliance, a 0.018- × 0.025-inch resilient mandibular archwire and a 0.017- × 0.022-inch resilient maxillary archwire are inserted. The loop stops are flush with the second molar tubes in each arch. The mandibular second molar receives an effective distal tip of 15 degrees from this initial archwire. In the maxillary arch, enough tip is in the wire distal to the loop to have an effective distal tip of 5 degrees on the second molar. The objective in each respective arch is to maintain the maxillary molar in its distally tipped position and to begin tipping the mandibular second molar to an anchorage prepared position.

A second premolar offset bend is placed mesial to the second premolar bracket in each archwire. The purpose of this bend is to prevent the canines from expanding out of the alveolar trough as they are retracted with the headgear. The third-order bends in each archwire are passive. High-pull J-hook headgear is used to retract maxillary and mandibular canines. After each month of treatment, both archwires are removed and the terminal molar tip in the mandibular archwire is increased to maintain the effective 15-degree tip as the tooth tips distally. After the first month of treatment the maxillary first molars are banded, and after the second month of treatment the mandibular first molars are banded. As the canines retract and the arches are leveled, the lateral incisors are ligated, and power chain force to aid canine retraction can be used (Figure 15-28).

One must remember that at each visit during denture preparation, the archwires are removed; carefully coordinated; checked for proper first-, second-, and third-order bends; and religated. Canine retraction is continued with power chain and headgear force. At the end of the denture preparation stage of treatment the dentition should be level, the canines should be retracted, all rotations should be corrected, and the mandibular terminal molars should be tipped distally into an anchorage prepared position (Figure 15-29).

Denture Correction

The second step of treatment is called denture correction. During denture correction, the spaces are closed with

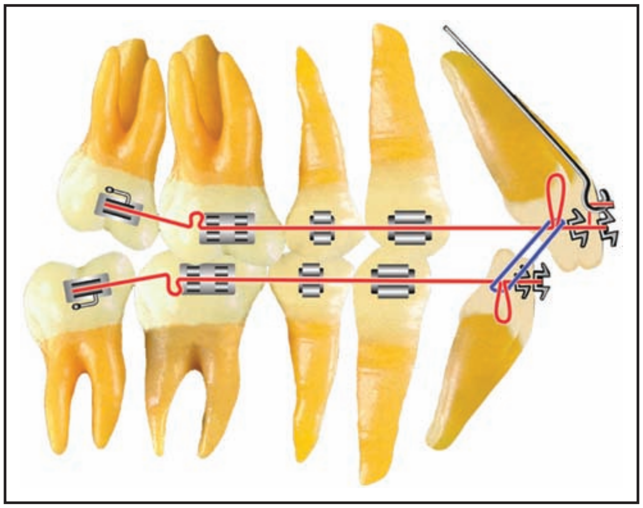


FIGURE 15-30 Denture correction: closing loop application. Maxillary and mandibular closing loops are used to close space mesial to the distalized canines.

maxillary and mandibular closing loop archwires. Vertical support to the maxillary arch is achieved with J-hook headgear attached to hooks soldered to the maxillary archwire between the maxillary central and lateral incisors. Vertical support of the mandibular anterior teeth is accomplished with anterior vertical elastics. The mandibular archwire is a 0.019- × 0.025-inch working archwire with 6.5-mm vertical loops distal to the lateral incisor brackets. The 0.020- × 0.025-inch maxillary archwire has 7.5-mm vertical loops distal to the lateral incisor brackets. In both arches the loop stops are immediately distal to the brackets of the first molars (Figure 15-30). The loop stop in the mandibular archwire incorporates a compensation to maintain the 15-degree terminal molar tip. After each activation, the archwire is removed and the compensating height of the distal leg of the loop stop in the mandibular archwire is reduced so that the archwire remains passive to the previously tipped second molar. The maxillary archwire is coordinated with the mandibular archwire and activated each month until all maxillary space is closed. At the end of space closure (Figure 15-31), the curve of occlusion in the maxillary arch should have been maintained, and the mandibular arch should be completely level with a 15-degree distal tip in the second molar. The dentition is now ready for mandibular anchorage preparation. This step positions teeth in the mandibular midarch and posterior areas into axial inclinations that will allow final coordination with the maxillary teeth for normal functional occlusion.

Sequential Mandibular Anchorage Preparation. Sequential mandibular anchorage preparation is based on the concept of sequential tooth movement. The archwire produces an active force on only 2 teeth while remaining passive to the other teeth in the arch. Therefore the remaining teeth act as stabilizing or anchorage units as 2 teeth are tipped. The method is referred to as the "10-2" (10 teeth versus 2 teeth) anchorage system, and it allows a quickly controlled response without serious adverse reaction. The anchorage preparation system is supported by high-pull headgear worn on vertical spurs that are soldered distal and gingival to the mandibular central incisors.

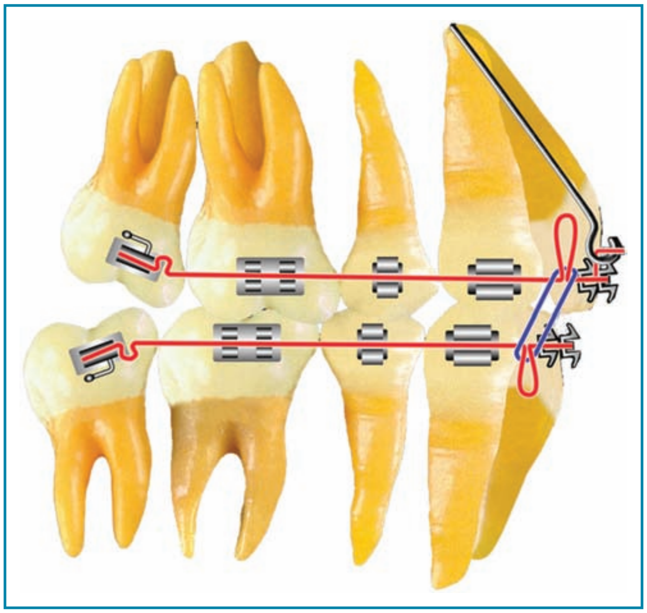


FIGURE 15-31 Space closure. After space closure the arch is level and the terminal molars remain tipped to an anchorage prepared position.

Sequential mandibular anchorage preparation is initiated during the denture preparation step of treatment by tipping the second molar to a 15-degree distal inclination. After closing the mandibular space, the orthodontist checks the arch to make sure that it is level and that the second molars are tipped to a 15-degree distal angulation. This procedure is referred to as readout.[47] At this time the second step of sequential mandibular anchorage preparation, first molar anchorage, is initiated. Another 0.019- × 0.025-inch archwire with the loop stops bent flush against the second molar tubes is fabricated. First- and third-order bends are ideal. Gingival hooks for high-pull J-hook headgear are soldered distal to the central incisors. To tip the first mandibular molars to an anchorage prepared position, a 10-degree distal tip is placed 1 mm mesial to the first molar brackets. A compensating bend that maintains the 15 degrees of terminal molar tip is placed just mesial to the loop stop. The archwire is now passive to the second molar and crosses the twin brackets of the first molar at a 10-degree bias (Figure 15-32, *A, B*). The second molars are now part of the 10 stabilizing units, and the first molars are the two teeth that receive the action of the directional forces and the archwire. After 1 month the archwire is removed and a readout should show a 5- to 8-degree distal inclination of the first molars. The second molars should continue to readout at 15 degrees.

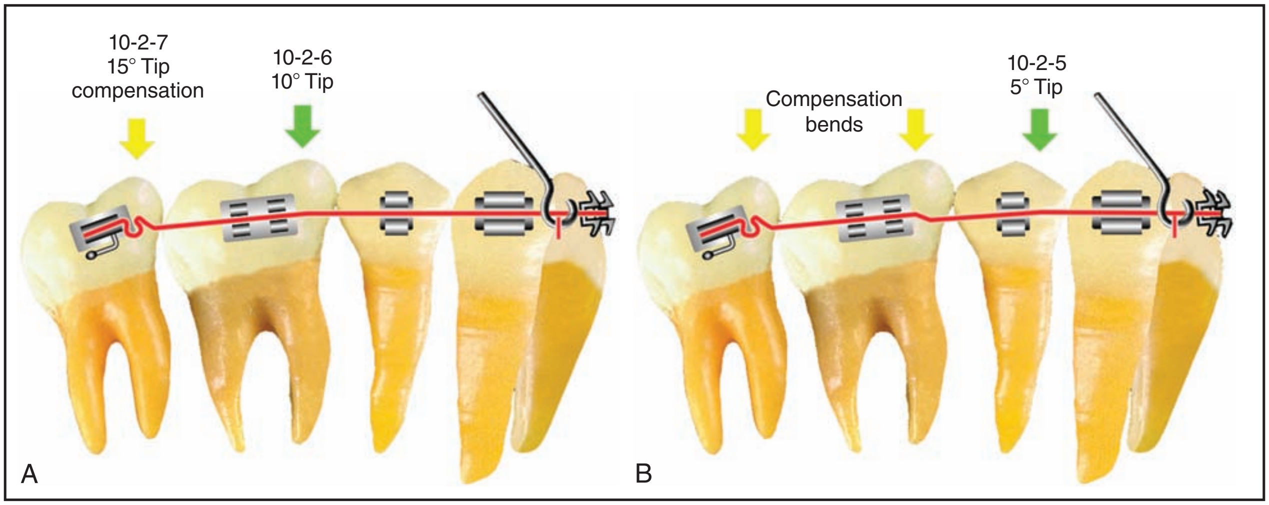


FIGURE 15-32 Mandibular anchorage preparation. **A,** 10-2-6. The first molar is tipped to its anchorage prepared position. **B,** 10-2-5. The second premolar is tipped to its anchorage prepared position.

The third and final step of sequential mandibular anchorage preparation is to place a 5-degree distal tip 1 mm mesial to the second premolar brackets. A compensating bend is placed mesial to the first molars to maintain them in their anchorage prepared position (see Figure 15-32, *B*). This bend allows the archwire in the second premolar area to be on a bias to the second premolar bracket when the archwire is seated in the second molar tubes and into the first molar brackets. The archwire must be passive in the brackets of the first molars and in the second molar tubes. The archwire is ligated, and again the high-pull headgear is worn on the spurs soldered to the mandibular archwire. Usually, wearing of headgear during sleeping hours only is effective. During this step of anchorage preparation, the first and second molars and the 6 anterior teeth are part of the 10 stabilizing units, while the 2 premolars are the recipients of the 10-2 directional force system. At the end of mandibular anchorage preparation a readout will show that the second molars have a distal axial inclination of 15 degrees, the first molars have a distal axial inclination of 5 to 8 degrees, and the second premolars are at 0 degrees or have a distal axial inclination of 3 degrees.

The denture correction step of treatment should now be complete for the Class I malocclusion. The objectives of the denture correction step are (1) complete space closure in both arches, (2) sequential anchorage preparation in the mandibular arch, (3) an enhanced curve of occlusion in the maxillary arch, and (4) a Class I intercuspation of the canines and premolars. The mesiobuccal cusp of the maxillary first molar should fit into the mesiobuccal groove of the mandibular first molar. The distal cusps of these teeth should be discluded, as should those of the second molars.

Class II Force System. For patients with an "end-on" or a full-step Class II dental relationship of the buccal segments at the conclusion of space closure, a new system of forces must be used to complete the denture correction stage of treatment. A careful study of the cusp relationships will determine the force system required. Making a final diagnostic decision for Class II correction is usually based on (1) the ANB relationship, (2) a maxillary posterior space analysis, and (3) patient cooperation. The following guidelines are used:

1. If the maxillary third molars are missing, or if the ANB is 5 degrees or less and the patient is cooperative, the system to be described will accomplish the best result. If the third molars are present and are approaching eruption, they should be removed to facilitate distal movement of the maxillary teeth.
2. If a cooperative patient has (a) a mild Class II dental relationship, (b) a normal vertical skeletal pattern (FMA of 28 degrees or less), (c) an ANB of 5 to 8 degrees, and (d) normally erupting maxillary third molars, the extraction of maxillary second molars is most advantageous. The force system to be described is used to distalize the maxillary dentition into the second molar extraction space.
3. If (a) the ANB is greater than 10 degrees, (b) maxillary third molars are present, and/or (c) the patient's motivation is questionable, the first molars should be considered for removal after maxillary and mandibular first premolar extraction space closure, or surgical correction should be considered. Facial balance and harmony "projections"after correction with either molar extraction or orthognathic surgery should be considered carefully before making either decision.

The Class II force system cannot be used unless compliance requirements are strictly followed by the patient. If one attempts to use the Class II force system without cooperation, the maxillary anterior teeth will be pushed forward off basal bone.

Orthodontic Correction of the Class II Dental Relationship. At the end of sequential mandibular anchorage preparation, a mandibular 0.0215 × 0.028 inch stabilizing archwire is fabricated. Ideal first-, second-, and third-order bends are incorporated into the archwire. The loop stop must be 0.5 mm short of the molar tubes, and the wire must be passive to all the brackets. Gingival spurs are soldered distal to the mandibular lateral incisors. The wire is seated and ligated, and the terminal molar is cinched tightly to the loop stop.

A 0.020- × 0.025-inch maxillary archwire with 7.5-mm closed helical bulbous loops bent flush against the second molar tubes is fabricated. The helix is wound to the lingual during fabrication. This archwire has ideal first- and second-order bends. The molar segment has 7 degrees of progressive lingual crown. A gingival spur is attached to the archwire immediately distal to the maxillary second premolar bracket. Gingival high-pull headgear hooks are soldered distal to the central incisors. Class II "lay on" hooks with a gingival extension for anterior vertical elastics are soldered distal to the lateral incisors. The closed helical bulbous loops are opened 1 mm on each side. The anterior segment of the archwire will be 1 millimeter labial to the maxillary incisor brackets. The archwire is ligated in place. Eight-ounce Class II elastics are worn from the hooks on the mandibular second molar tubes to the Class II hooks on the maxillary archwire. Anterior vertical elastics are worn from the spurs on the mandibular archwire to the gingival extension hooks on the maxillary archwire. The high-pull headgear is worn on the maxillary headgear hooks (Figure 15-33, *A*).

This force system is used for about 1 month to sequentially move the maxillary second molars distally. At the next appointment, the mandibular archwire is removed and checked, and the helical bulbous loops are again activated 1 mm. The activation of the maxillary archwire is repeated until the second molars have a Class I dental relationship (Figure 15-33, *B*). When the Class I relationship of the second molars has been established, a closed coil spring is "wound" distal to the second premolar spur and compressed between the spur and the first molar bracket when the maxillary archwire is inserted. (The coil spring length should be 1.5 times the space between the second premolar and the first molar brackets.) An elastic chain is stretched from the second molar to the distal bracket of the first molar. The spring and the elastic chain create a distal force on the maxillary first molar. Additionally, the Class II elastic is worn continuously from the mandibular second molar hook to the Class II hook on the maxillary archwire, and an anterior vertical elastic is worn 12 hours each day (Figure 15-34). The high-pull headgear is worn 14 hours per day on the spurs soldered to the maxillary archwire. This is an efficient force system for first molar distalization (Figure 15-35).

After the first molars are moved distally into an overcorrected Class I dental relationship, the spur that was attached distal to the second premolar bracket is removed. The coil spring is moved mesially so that it is compressed between the lay-on hook and the canine bracket. Subsequently, the maxillary second premolars and the maxillary canines are moved distally with elastic chain and headgear force (Figure 15-36). Four months of treatment with monthly reactivation should position the posterior teeth and the maxillary canine in an

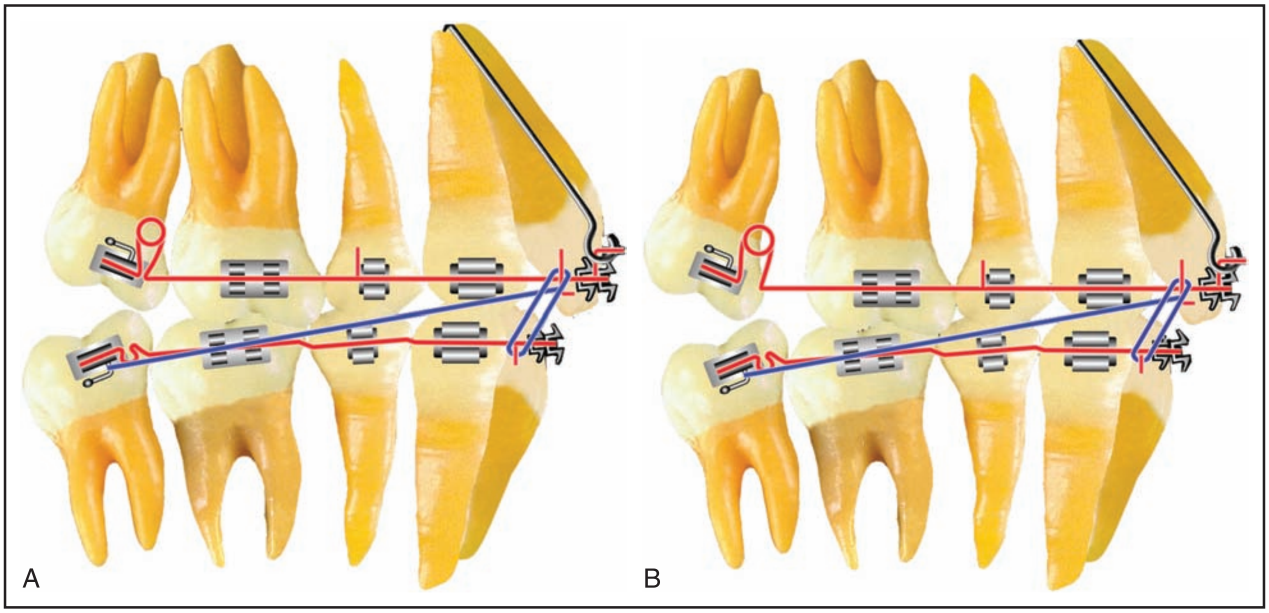


FIGURE 15-33 Class II force system. Denture correction: maxillary second molar distalization. **A,** Step 1. A helical bulbous loop is placed against the maxillary second molar. **B,** Step 2. The helical bulbous loop pushes the maxillary molar distally.

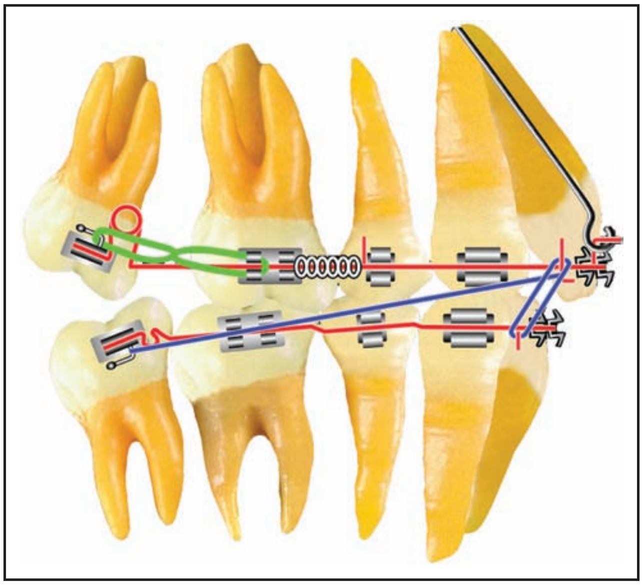


FIGURE 15-34 Class II force system. Denture correction: a coil spring is trapped mesial to the first molar.

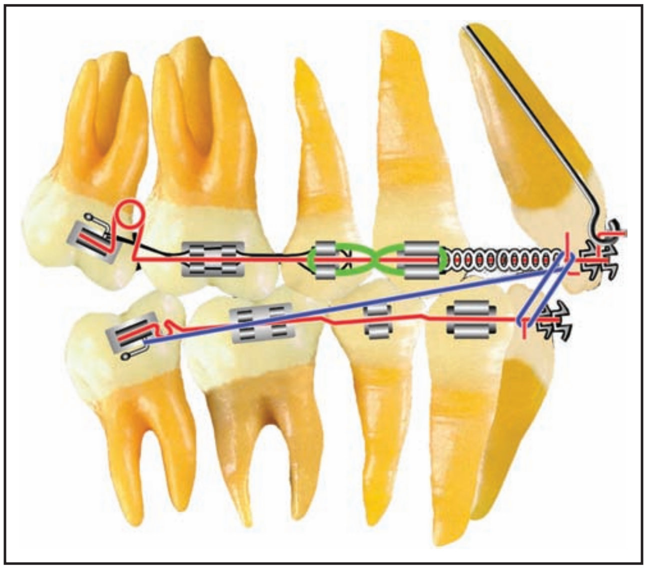


FIGURE 15-36 Class II force system. Denture correction: maxillary second premolar and maxillary canine distalization. After molar distalization the premolars and canines are distalized.

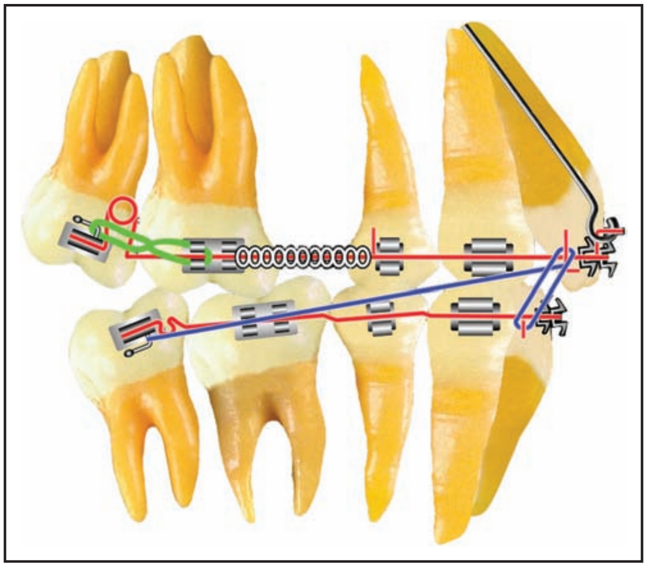


FIGURE 15-35 Class II force system. Denture correction: maxillary first molar distalization.

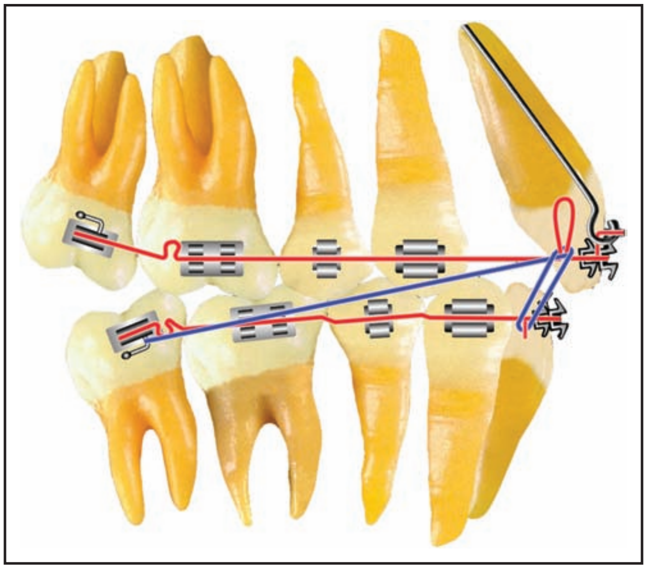


FIGURE 15-37 Class II force system. Denture correction: maxillary anterior space closure. A 0.020- × 0.025-inch maxillary closing loop archwire is used to close the maxillary anterior space.

overtreated Class I relationship. This system will not strain the mandibular arch if the anterior vertical elastics are worn and if sufficient space is available in the maxillary posterior denture area.

After overcorrection of the Class II dental relationship an 0.020- × 0.025-inch maxillary archwire with 7.5-mm closing loops distal to the lateral incisors is fabricated. This archwire has ideal first-, second-, and third-order bends. Gingival headgear hooks are soldered distal to the central incisors (Figure 15-37). The closing loops are opened 1 mm per visit by cinching the loop stops to the molar tube. The Class II force should be milder: 4 to 6 oz instead of 6 to 8 oz. The anterior vertical elastic and the maxillary high-pull headgear are used along with these light Class II elastics. After all the maxillary space is closed, the step of denture correction has been completed, and the dentition is ready for the next step of treatment—denture completion.

Denture Completion

The third step of treatment is identified as denture completion. Ideal first-, second-, and third-order bends are placed in the finishing mandibular and maxillary 0.0215- ×0.028-inch resilient archwires. The mandibular archwire duplicates the previously used mandibular stabilizing archwire. The maxillary archwire has artistic bends and hooks for the high-pull headgear, anterior vertical elastics, and Class II elastics. Supplemental hooks for vertical elastics are soldered as needed (Figure 15-38).

The forces used during denture completion are based on a careful study of the arrangement of each tooth in each arch. The orthodontist must also study the relationship of one arch to the other and the relationship of the arches to their environment. The orthodontist makes necessary first-, second-, and third-order adjustments in each archwire as needed. A progress cephalogram and tracing can be evaluated to determine the final mandibular incisor position and any minor control of the palatal, occlusal, and mandibular planes that may be needed. Study of the tracing also may reveal to the clinician the requirement for lingual root torque in the maxillary incisors. Visual clinical observations permit evaluation of the lip line, the maxillary incisor relationship, and the amount of cusp seating and artistic positioning of the incisors that is necessary.

Denture completion can be considered as minitreatment of the malocclusion. During this treatment step, the orthodontist uses the forces that are necessary until the original malocclusion is overcorrected. At the end of the denture completion stage of treatment, the following characteristics should be readily observed:

1. The incisors must be aligned.
2. The occlusion must be overtreated to a Class I relationship.
3. The anterior teeth must have minimal incisal guidance.
4. The maxillary canines and second premolars must be locked tightly into a Class I dental relationship.
5. The mesiobuccal cusp of the maxillary first molar must occlude in the mesiobuccal groove of the mandibular first molar.
6. The distal cusps of the first molars and the second molars should be slightly out of occlusion.
7. All spaces must be closed tightly from the second premolars forward.

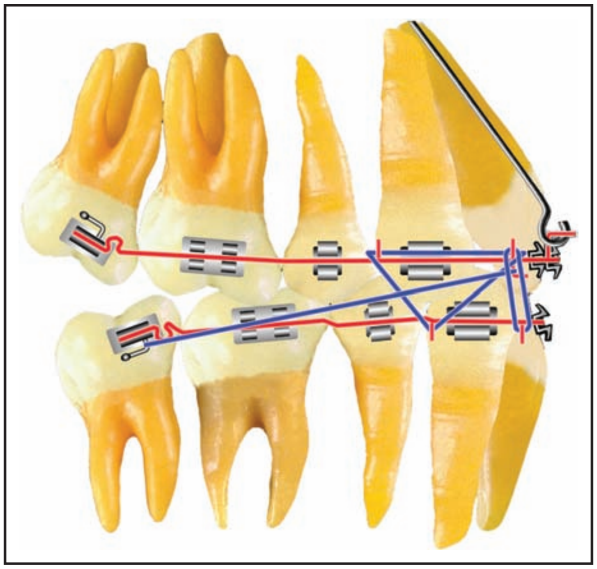


FIGURE 15-38 Denture completion. Maxillary and mandibular stabilizing wires, along with the proper elastics and headgear force, are used to complete the orthodontic treatment.

Denture Recovery

The ideal occlusion will occur after all treatment mechanics are discontinued and uninhibited function and other environmental influences active in the posttreatment period stabilize and finalize the position of the total dentition. When all appliances are removed and the retainers are placed, a most crucial “recovery” phase occurs. During this recovery period, the forces involved are those of the surrounding environment, primarily the muscles and the periodontium. If mechanical corrective procedures barely achieve normal relationships of the teeth, relapse is inevitable. Any change is likely to be away from ideal occlusion toward malocclusion. Recovery, based on a concept of overcorrection, is predicated on clinical experience and research.

The posttreatment occlusion, which is carefully planned, sometimes referred to as Tweed occlusion but properly identified as transitional occlusion (Figure 15-39), is characterized by disclusion of the second molars. The mesiolingual cusp of the maxillary first

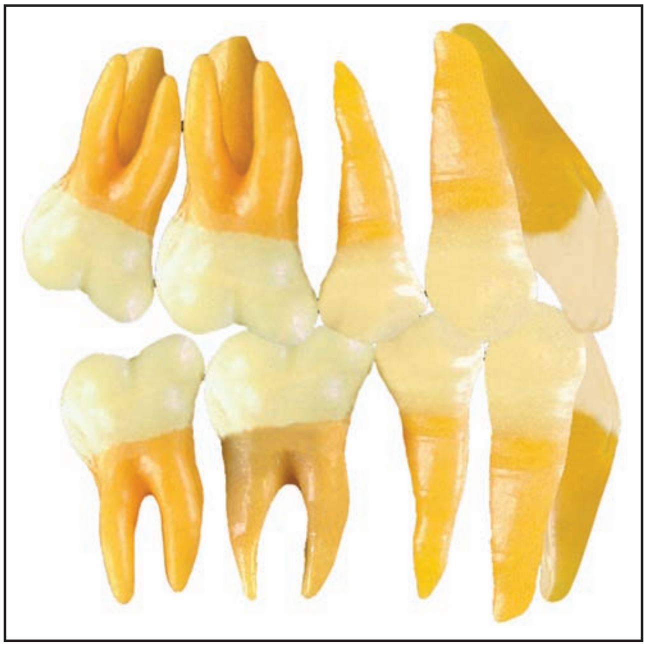


FIGURE 15-39 Transitional occlusion. The occlusion must be overtreated to a Class I relationship. The anterior teeth should be edge to edge. The canines, second premolars, and first molars must have a solid Class I dental relationship. The second molars should be tipped out of occlusion.

molar is seated into the central fossa of the mandibular first molar with the mesial inclined plane of the mesial cusp of the maxillary first molar contacting the distal inclined plane of the mesial cusp of the mandibular first molar. This arrangement allows the muscles of mastication to effect the greatest force on the "primary chewing table" in the midarch area. The slightly intruded distally inclined maxillary and mandibular second molars now can "reerupt" to a healthy functional occlusion without trauma or premature contact. Because of overtreatment of Class I and Class II deep-bite patients, the anterior teeth are positioned in an end-to-end relationship with no overbite or overjet. This relationship, however, is transitory and will adjust rapidly to an ideal overjet and overbite relationship (Figure 15-40).

The muscles of swallowing, expression, and mastication are involved actively in determining the final stable, aesthetic relationship of the teeth, referred to as functional occlusion. This concept of a transitional occlusion followed by a period of recovery is based on the belief that each individual's oral environment will determine the ultimate position of the dentition and that overtreatment allows the patient the greatest opportunity for maximum stability and functional efficiency.

The correction of three distinctly different types of malocclusions is illustrated. Two of these malocclusions, patients MK and TK, were treated recently. The intent of showing MK's records is to illustrate the fact that all treatment objectives can be routinely obtained in the treatment of a very difficult malocclusion if the force system that has been presented is used. The treatment planning of MK's malocclusion is described in detail to illustrate the use of the craniofacial analysis and the total dentition space analysis. This malocclusion was a severe Angles Class II division I with facial imbalance. The Class II force system, which has been described in this chapter, was used after all premolar extraction spaces had been closed. Because this patient was recently treated, her casts reflect the transitional occlusion that will settle into the final occlusion.

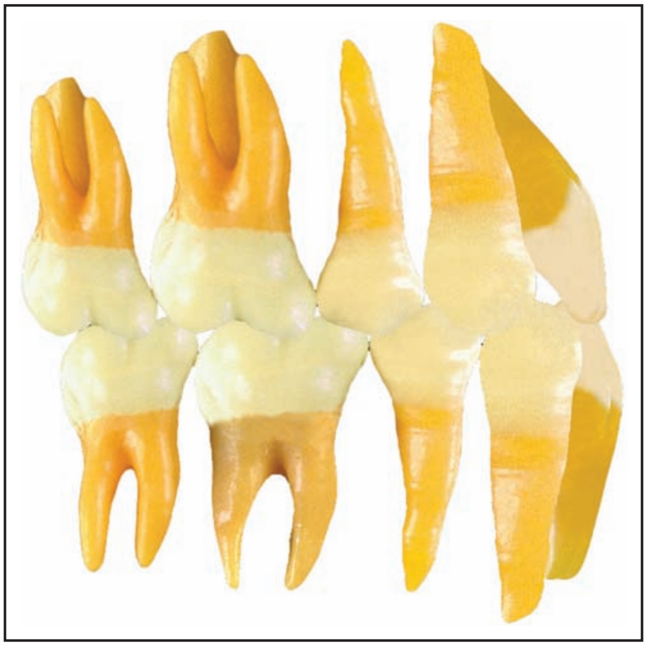


FIGURE 15-40 Final occlusion is characterized by the teeth settling into their most efficient, healthy, and stable positions.

The second case report, LS, is presented to illustrate the carefully planned correction of a malocclusion that was treatment-planned for the extraction of the maxillary first and mandibular second premolars. The clinician's goal was to maintain the beautiful face and to correct the dental disharmony. The Tweed Merrifield force system that was used to protract the mandibular first molars is described. This case report is also being used to illustrate the fact that long-term retention is a very viable and realistic goal if the treatment plan is properly determined and if the force systems are correctly applied. Long-term stability must be an achievable goal for all clinical orthodontists and for the orthodontic patient. Without long-term stability as a goal, the benefit of orthodontic treatment rendered to the patient would not be worth the burdens of treatment.

CASE REPORT 15-2 CASE REPORTS: MALOCCLUSION CORRECTION WITH THE EDGEWISE APPLIANCE

Patient: MK

Diagnosis

This recently treated 13-year-old girl presented with a malocclusion that reflected facial, dental, and craniofacial disharmony. Profile and full-face black and white photographs (Figure 15-41) illustrate the protrusion and the facial imbalance. The patient has excessive gingival display on smiling. The casts (Figure 15-42) exhibit the Angle's Class II occlusion with a deep impinging overbite and flared and protrusive maxillary and mandibular incisors. The pretreatment tracing of the cephalogram (Figure 15-43) shows an ANB of 10 degrees and an AO-BO of 7 mm, indications of the severity of the Class II malocclusion. The FMIA of 50 degrees and Z angle of 53 degrees are reflections of the protrusive face. The IMPA of 105 degrees confirms mandibular incisors that are forward of their bony support. The differential diagnostic analysis system was used to give some objectivity to the patient's diagnosis. The craniofacial analysis shows a cranial facial difficulty total of 109 (Figure 15-44). The difficulty is in two areas: the ANB and the Z angle. All other values are within normal range. The total space analysis confirms the severity of the dental problem with a cephalometric discrepancy of 13.6 mm, a curve of Spee correction of 2 mm, and a Class II correction of 8 mm. Using the difficulty values, total anterior discrepancy was 15.1 mm. The total midarch and occlusal disharmony discrepancy was 18 mm. The posterior discrepancy was 10 mm with a difficulty of only 5 because posterior discrepancies can normally be solved with third-molar extractions. The total space analysis difficulty was 38.1 mm. This value includes the space

CASE REPORT 15-2 CASE REPORTS: MALOCCLUSION CORRECTION WITH THE EDGEWISE APPLIANCE—cont'd

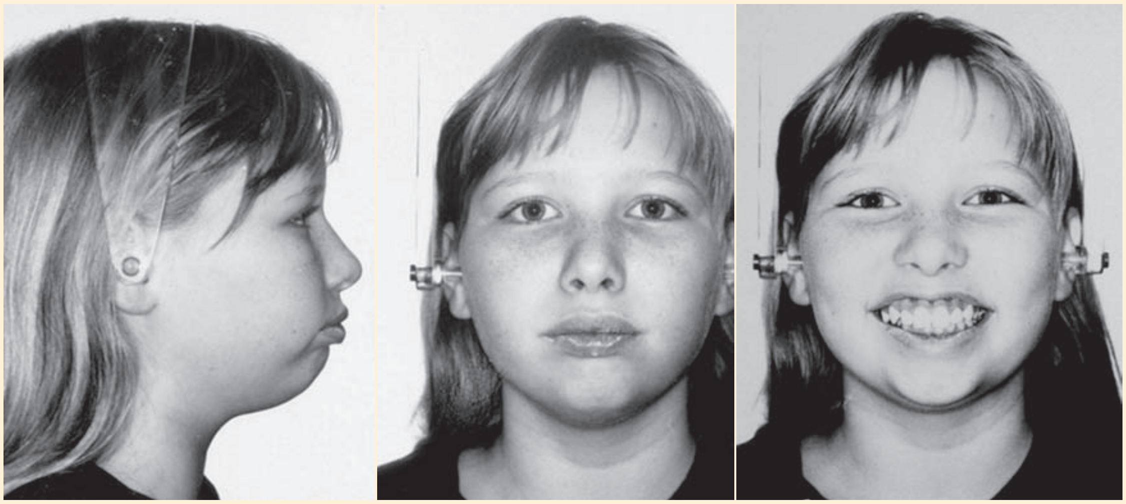


FIGURE 15-41 Pretreatment facial photographs

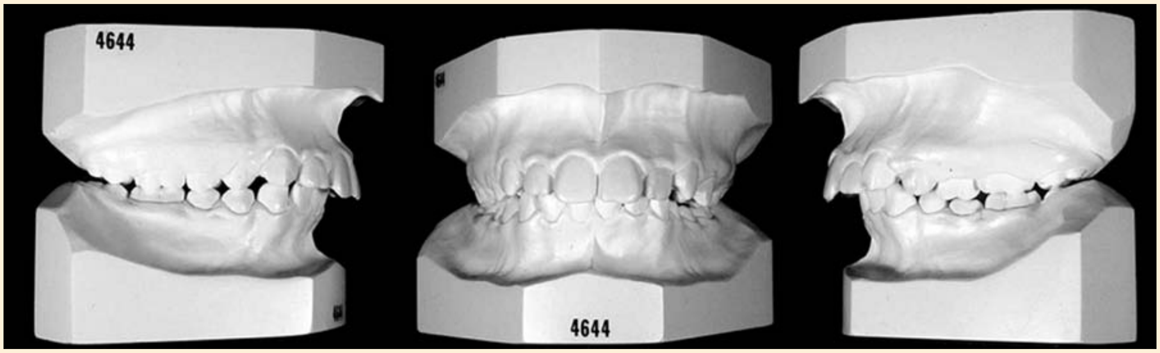
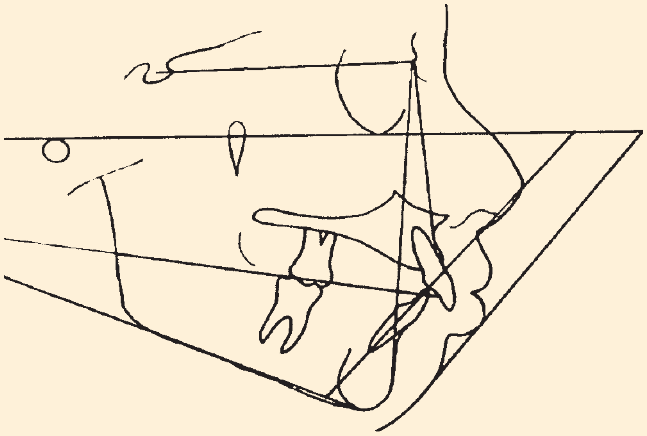


FIGURE 15-42 Pretreatment casts.



FMIA	50	AO-BO	7 mm
FMA	25	Z	53
IMPA	105	UL	10 mm
SNA	93	TC	9 mm
SNB	83	PFH	44 mm
ANB	10	AFH	58 mm

FIGURE 15-43 Pretreatment cephalometric tracing.

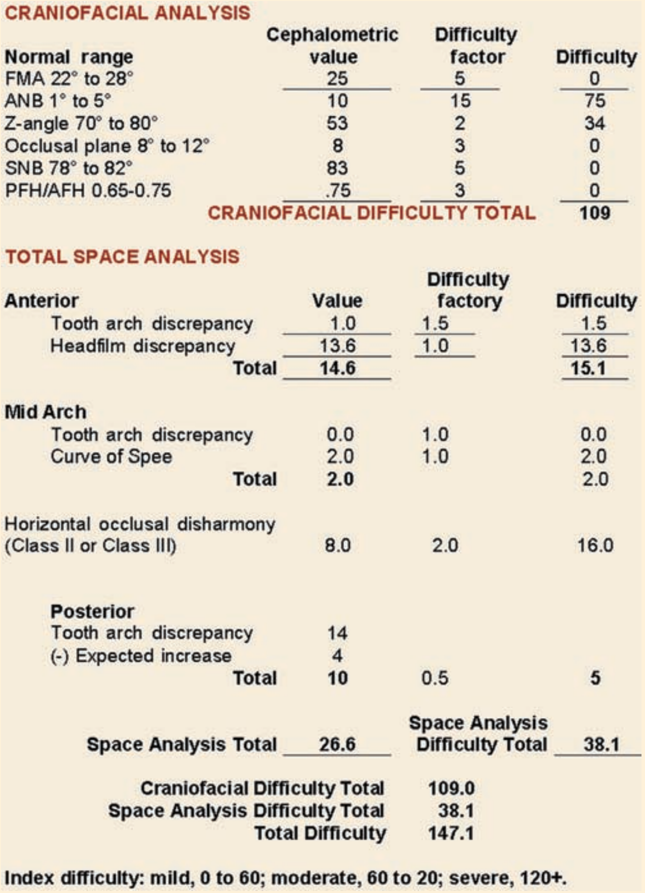
analysis difficulty and the occlusal disharmony difficulty. The 38.1 reflects the severe protrusion and Class II occlusion problem. The craniofacial difficulty of 109 is added to the space analysis difficulty of 38.1 to give a total difficulty of 147.1. This difficulty value puts the patient in the severe category and makes it evident to the clinician that the malocclusion correction is going to require skill with force-system application and good patient cooperation.

Treatment Plan and Treatment

Because of the severe protrusion and the immediate need to upright the mandibular incisors, the maxillary and mandibular first premolars were extracted. The patient was banded and bonded according to the protocol that has been described. The force system that has been described was used. The patient's malocclusion was corrected after 26 months of active appliance therapy. The patient's posttreatment facial photographs (Figure 15-45, *A–B*), when compared with the pretreatment photographs, exhibit a significant and positive change in the facial balance. The protrusion no longer exists and the patient has a pleasing profile. The pretreatment/posttreatment casts (Figure 15-46, *A–B*) exhibit control of the dentition; the creation of an ideal Angle's Class I dental relationship and the distal tipping of the second mandibular molars should be noted. These teeth have been tipped out of

Continued

CASE REPORT 15-2 CASE REPORTS: MALOCCLUSION CORRECTION WITH THE EDGEWISE APPLIANCE—cont'd



CRANIOFACIAL ANALYSIS

Normal range	Cephalometric value	Difficulty factor	Difficulty
FMA 22° to 28°	25	5	0
ANB 1° to 5°	10	15	75
Z-angle 70° to 80°	53	2	34
Occlusal plane 8° to 12°	8	3	0
SNB 78° to 82°	83	5	0
PFH/AFH 0.65-0.75	.75	3	0
CRANIOFACIAL DIFFICULTY TOTAL			**109**

TOTAL SPACE ANALYSIS

	Value	Difficulty factory	Difficulty
Anterior			
Tooth arch discrepancy	1.0	1.5	1.5
Headfilm discrepancy	13.6	1.0	13.6
Total	**14.6**		**15.1**
Mid Arch			
Tooth arch discrepancy	0.0	1.0	0.0
Curve of Spee	2.0	1.0	2.0
Total	**2.0**		2.0
Horizontal occlusal disharmony (Class II or Class III)	8.0	2.0	16.0
Posterior			
Tooth arch discrepancy	14		
(-) Expected increase	4		
Total	**10**	0.5	**5**
Space Analysis Total	**26.6**	**Space Analysis Difficulty Total**	**38.1**

Craniofacial Difficulty Total	**109.0**
Space Analysis Difficulty Total	**38.1**
Total Difficulty	**147.1**

Index difficulty: mild, 0 to 60; moderate, 60 to 20; severe, 120+.

FIGURE 15-44 Total difficulty analysis.

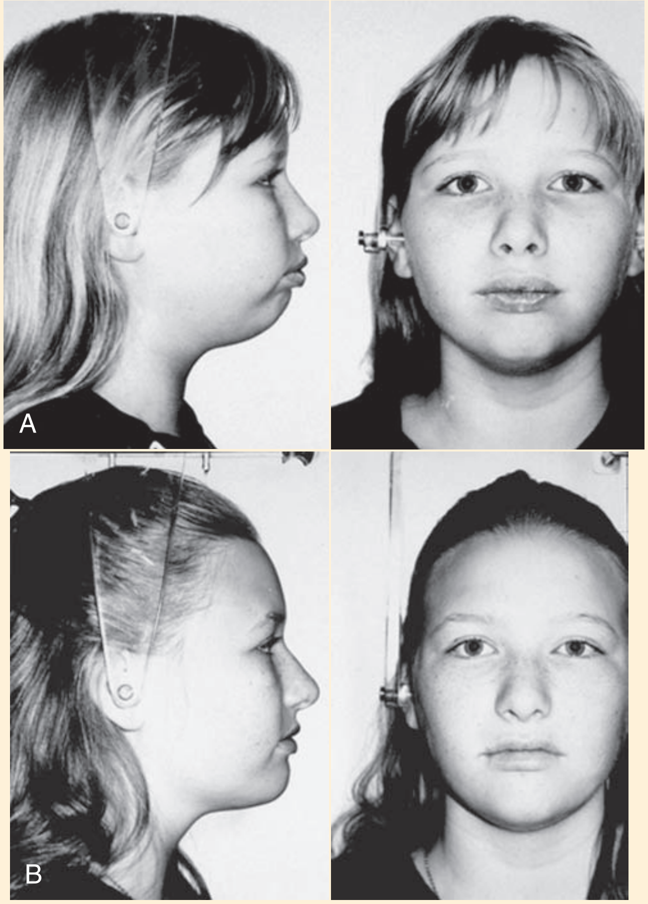


FIGURE 15-45 Pretreatment/posttreatment facial photographs.

occlusion because of anchorage preparation that enhanced vertical control during Class II correction. The pretreatment/posttreatment cephalogram tracings (Figure 15-47, *A–B*) illustrate changes in many of the values. The FMIA increased from 50 to 66 degrees. Mandibular incisors were uprighted from 105 to 91 degrees, and ANB was reduced from 10 to 3 degrees. The Z angle increased from 53 to 75 degrees, a clear indication that the goals for facial balance and harmony were met. Superimposition tracings (Figure 15-48) illustrate the control of the maxillary and mandibular molars, uprighting of the mandibular incisors, and the upward and backward movement of the maxillary incisors. The direction of mandibular response was downward and forward. This downward and forward mandibular response contributed greatly to the improved facial balance and harmony. The smiling photographs of the patient (Figure 15-49) confirm the intrusion of the incisors and a considerable decrease in gingival display.

CASE REPORT 15-2 CASE REPORTS: MALOCCLUSION CORRECTION WITH THE EDGEWISE APPLIANCE—cont'd

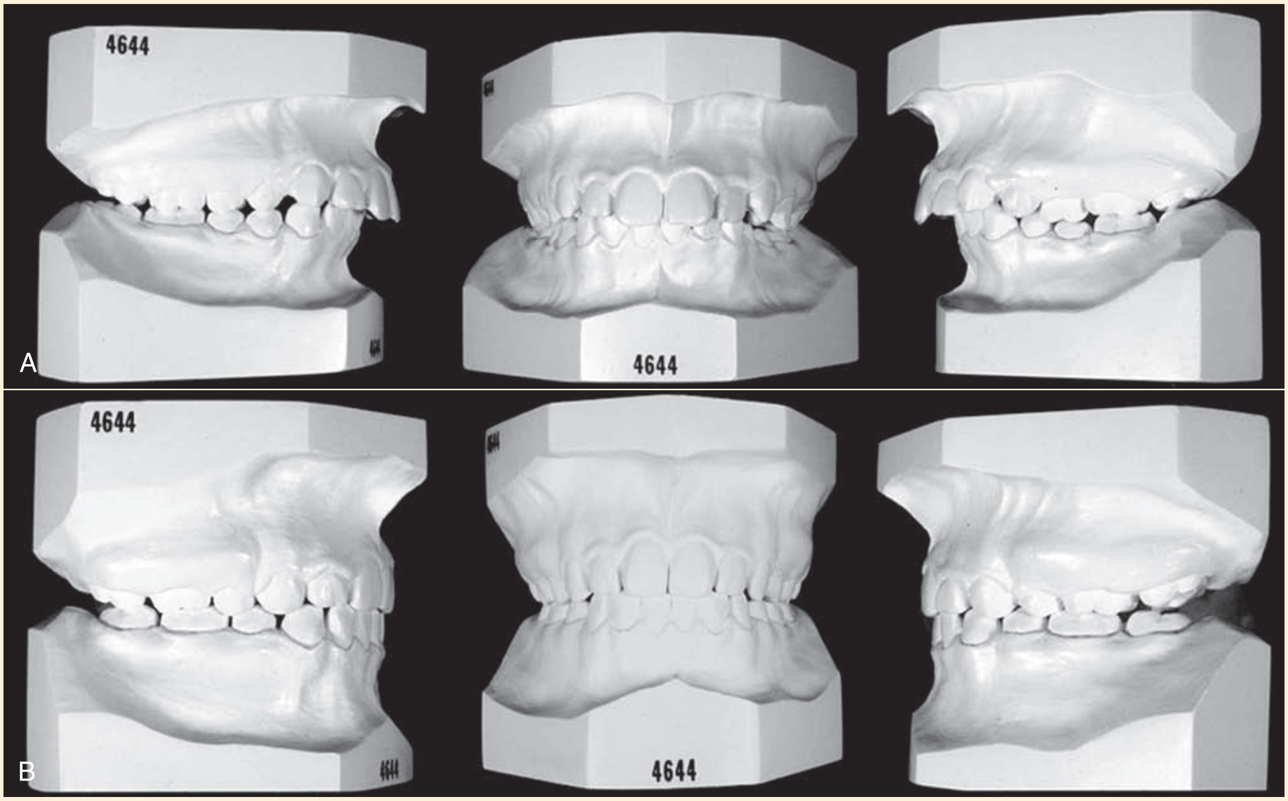
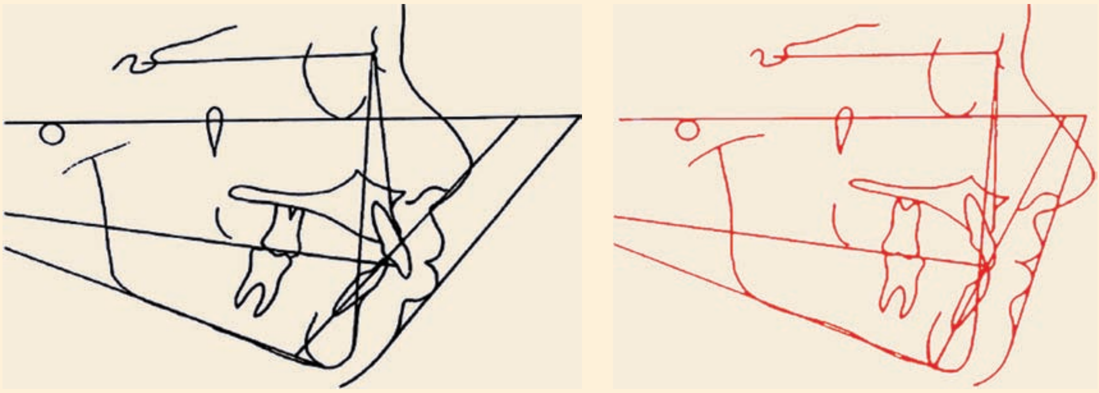


FIGURE 15-46 Pretreatment/posttreatment casts.



A

FMIA	50	AO-BO	7.mm
FMA	25	Z	53
IMPA	105	UL	10.mm
SNA	93	TC	9.mm
SNB	83	PFH	44.mm
ANB	10	AFH	58.mm

B

FMIA	66	OCC	7
FMA	23	Z	75
IMPA	91	UL	13.mm
SNA	88	TC	12.mm
SNB	85	PFH	52.mm
ANB	3	AFH	63.mm
AO-BO	2 mm		

FIGURE 15-47 Pretreatment/posttreatment cephalometric tracings.

Continued

CASE REPORT 15-2 **CASE REPORTS: MALOCCLUSION CORRECTION WITH THE EDGEWISE APPLIANCE—cont'd**

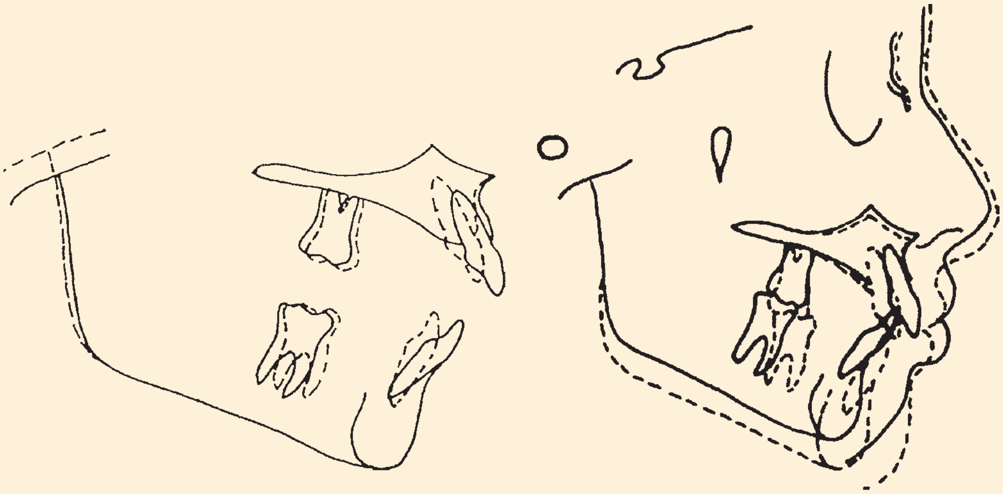


FIGURE 15-48 Pretreatment/posttreatment superimpostitions.

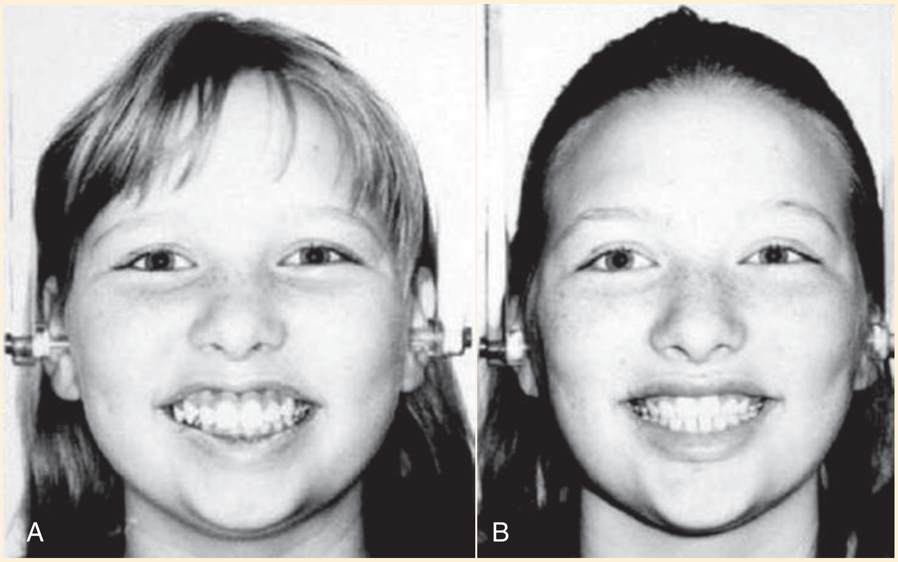


FIGURE 15-49 Pretreatment/posttreatment smiling photographs.

CASE REPORT 15-2

CASE REPORTS: MALOCCLUSION CORRECTION WITH THE EDGEWISE APPLIANCE—cont'd

Patient: LS

The patient whose treatment plan requires the extraction of maxillary first premolars and mandibular second premolars generally has the following characteristics: (1) Balance and harmony of the lower face (Figure 15-50) is generally within reasonable limits. There is an "acceptable" relationship of the profile line to the lips and to the nose. In other words, these patients do not exhibit a great degree of unbalance of the lower face. (2) The dentition (Figure 15-51) is generally characterized by a Class II dental relationship and mild mandibular and/or maxillary anterior crowding. Many of these patients have a protrusion of the maxillary anterior teeth. (3) The cephalometric examination of the skeletal pattern most often reveals a moderate mandibular plane angle, mandibular incisors that are "reasonably upright" over basal bone, and a discrepancy in the anteroposterior relationship of the mandible to the maxilla. In our example, patient LS has an ANB of 7 degrees, an FMIA of 65 degrees and an IMPA of 85 degrees (Figure 15-52). These are values that one would expect for patients who "fit" into this facial, skeletal and dental pattern.

When making the differential diagnosis, it is important to understand the relationship of the mandible to the maxilla and the relationship of the teeth to the face. In this particular example, patient LS,

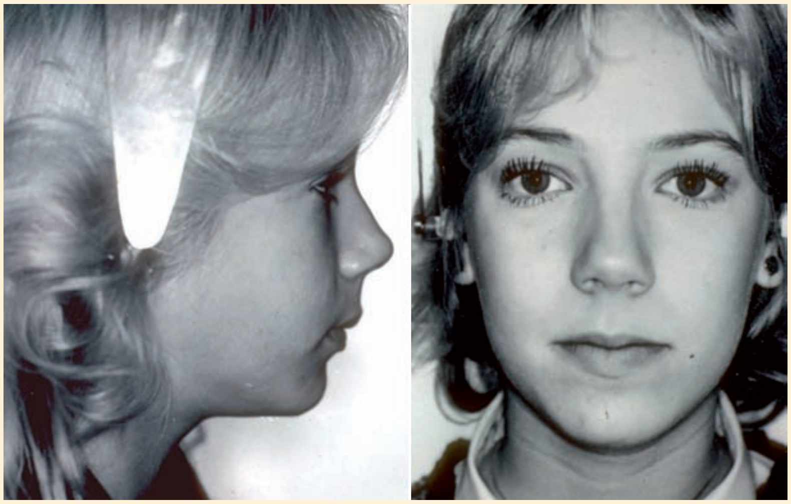


FIGURE 15-50 Pretreatment facial photographs.

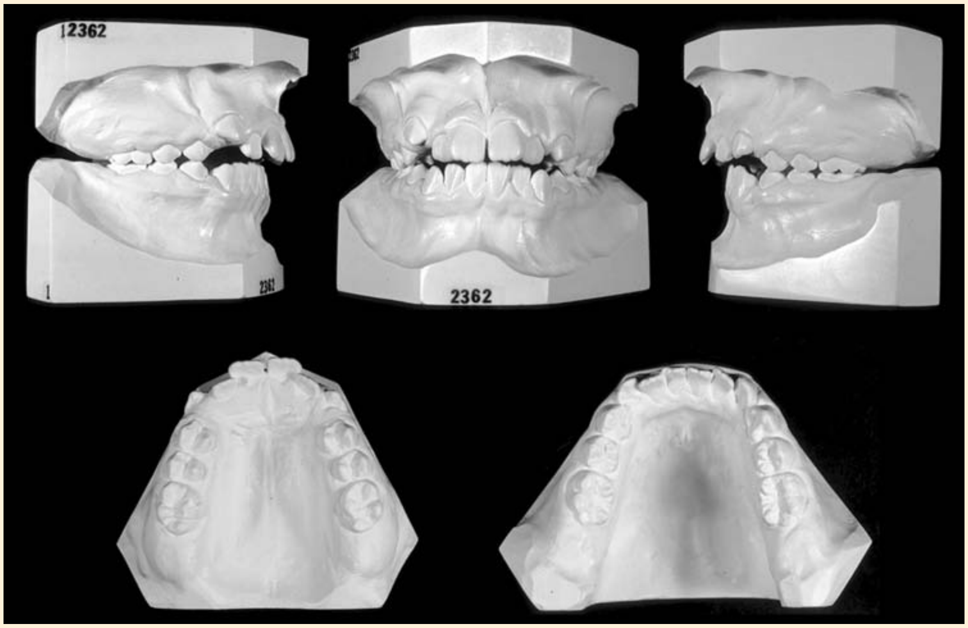


FIGURE 15-51 Pretreatment casts.

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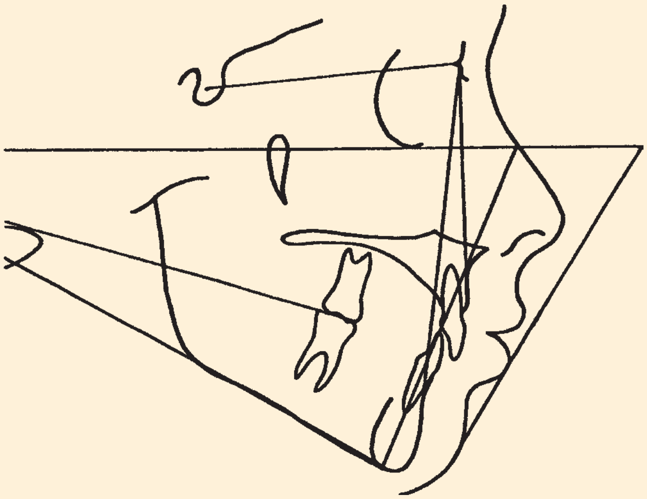


FMIA	65	OCC	14
FMA	30	Z	58
IMPA	85	UL	14.mm
SNA	85	TC	12.mm
SNB	78	PFH	42.mm
ANB	7	AFH	61.mm
AO-BO	4 mm	INDEX	68

FIGURE 15-52 Pretreatment cephalometric tracing.

the FMIA, Tweed's "facial angle," must be increased if the patient is to have improved balance and harmony in the lower face. Patient LS was treated with the extraction of the maxillary first premolars and the mandibular second premolars. The mandibular incisors were uprighted, the posterior occlusion was corrected by mesial movement of the mandibular posterior teeth, and crowding was ameliorated. The mesialization of the mandibular first molar is accomplished with a variation of the mandibular arch wires used during denture preparation (Figure 15-53, *A*–*C*). This system, designed by Klontz,[20] is based on control of the mandibular anterior and posterior teeth as the second premolar extraction space is closed. As the mandibular first molar is protracted, the second molar drifts mesially. When the mandibular space is closed the second molar is banded, mandibular anchorage is prepared, and treatment is finished with the arch wires that have been previously described.

The pretreatment/posttreatment facial photographs (Figure 15-54) illustrate improvement in balance and harmony of the lower face. The chin is not as recessive, and there is a nicer curl in the maxillary lip and less eversion of the lower lip. The pretreatment/posttreatment casts (Figure 15-55, *A*–*B*) confirm correction of the posterior occlusion, crowding amelioration and maintenance of arch form and arch width. The pretreatment/posttreatment cephalometric tracings (Figure 15-56, *A*–*B*) confirm mild uprighting of the mandibular incisors, an increase in FMIA from 65 degrees to 67 degrees, maintenance of the mandibular plane angle, and reduction of the ANB from 7 degrees to 3 degrees due to retraction of point A. The superimpositions (Figure

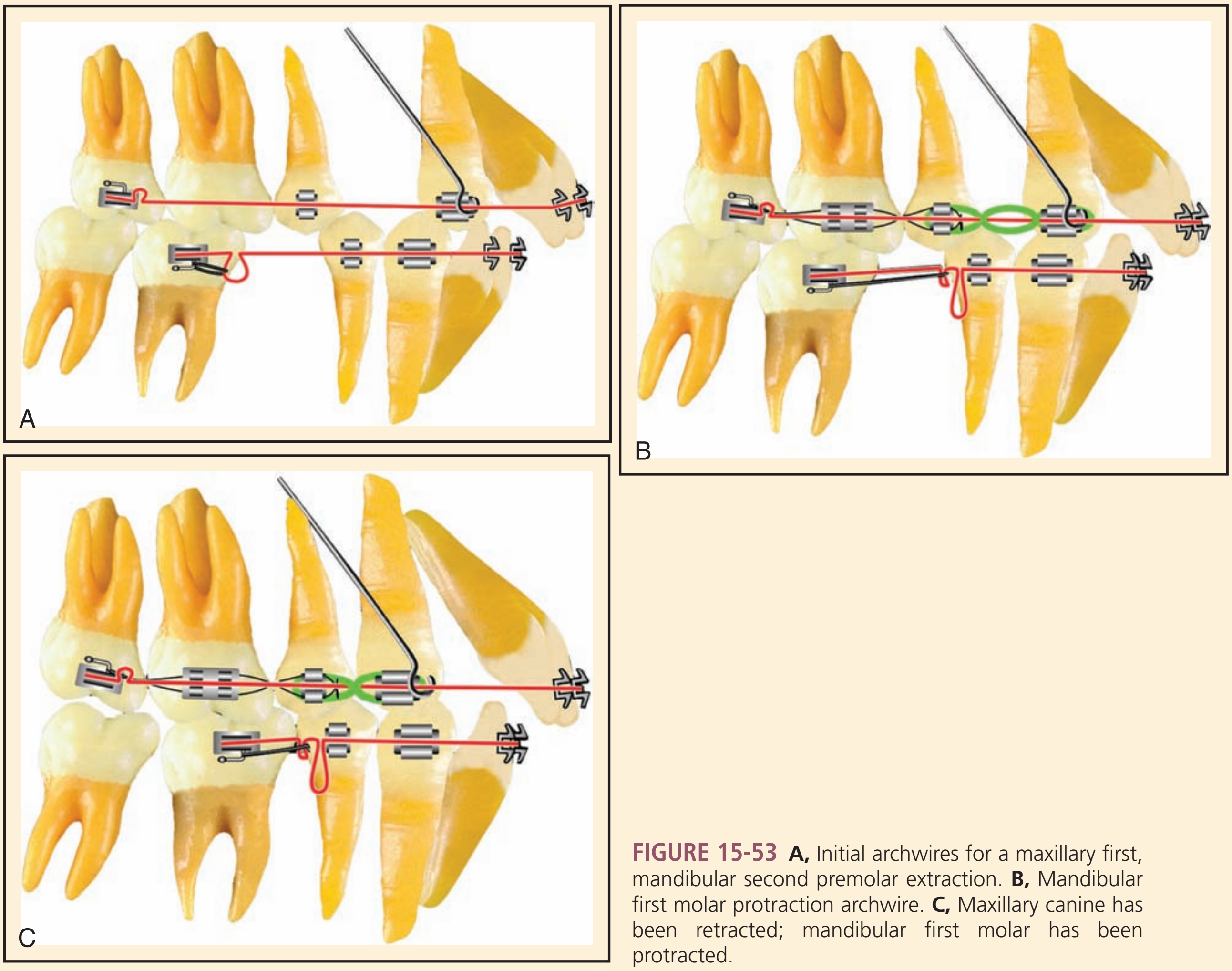


FIGURE 15-53 **A,** Initial archwires for a maxillary first, mandibular second premolar extraction. **B,** Mandibular first molar protraction archwire. **C,** Maxillary canine has been retracted; mandibular first molar has been protracted.

15-57) confirm a nice spatial change of the mandible in its relationship to the maxilla, vertical control of the molars, mild uprighting of the mandibular incisors and intrusion and retraction of the maxillary incisors.

Recall records of patient LS were made 10 years after treatment. The facial photographs (Figure 15-58) exhibit balance and harmony of the lower face and a wonderful, broad smile. The recall casts (Figure 15-59) illustrate excellent stability. The pretreatment/posttreatment/recall cephalogram superimposition tracing (Figure 15-60) confirms continued improvement in the spatial relationship of the mandibular to the maxilla and the concomitant improvement in balance and harmony of the lower face.

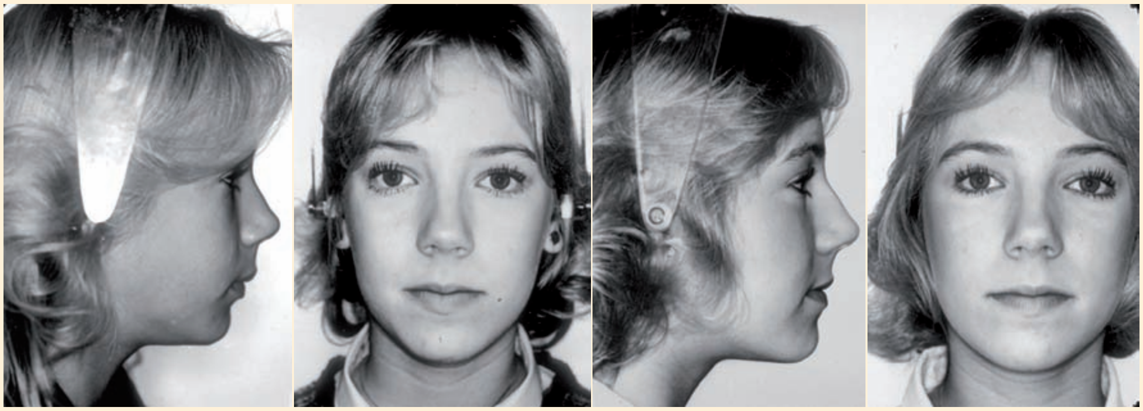


FIGURE 15-54 Pretreatment facial photographs.

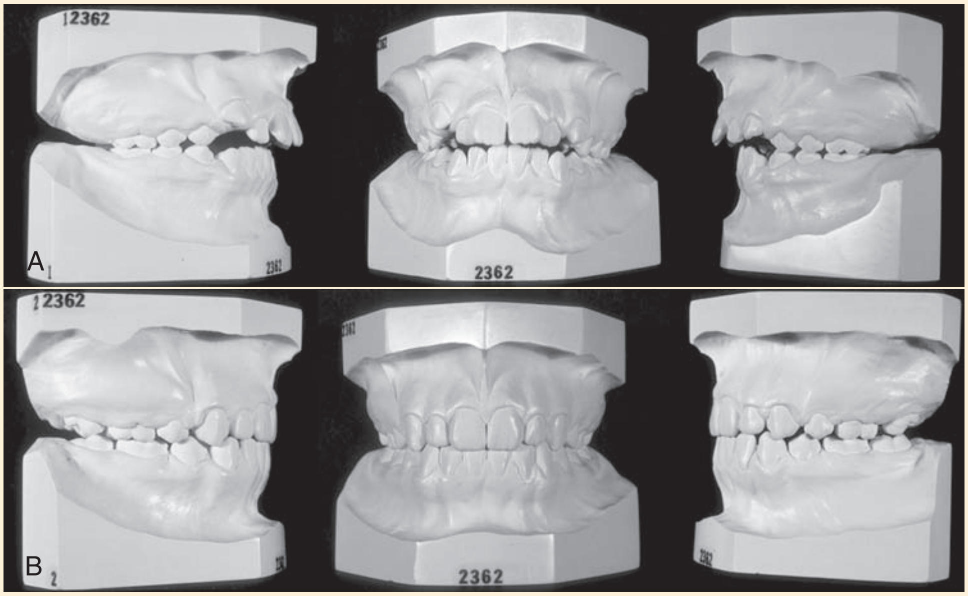
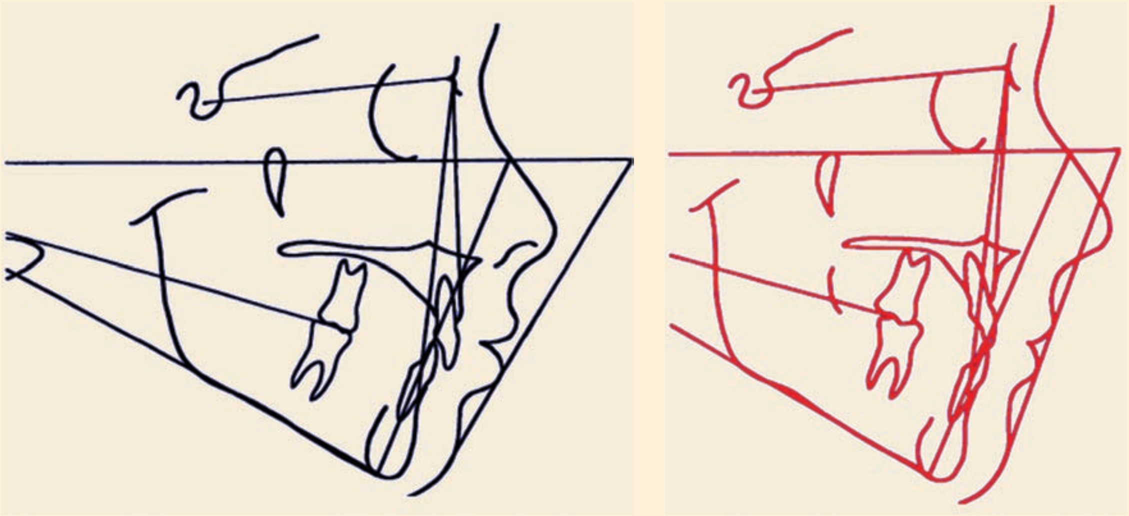


FIGURE 15-55 Pretreatment casts.

Continued

CASE REPORT 15-2

CASE REPORTS: MALOCCLUSION CORRECTION WITH THE EDGEWISE APPLIANCE—cont'd



A

FMIA	65	OCC	14
FMA	30	Z	58
IMPA	85	UL	14.mm
SNA	85	TC	12.mm
SNB	78	PFH	42.mm
ANB	7	AFH	61.mm
AO-BO	4 mm	INDEX	68

B

FMIA	67	OCC	13
FMA	30	Z	72
IMPA	83	UL	12.mm
SNA	82	TC	11.mm
SNB	79	PFH	45.mm
ANB	3	AFH	64.mm
AO-BO	3 mm	INDEX	70

FIGURE 15-56 Pretreatment cephalometric tracings.

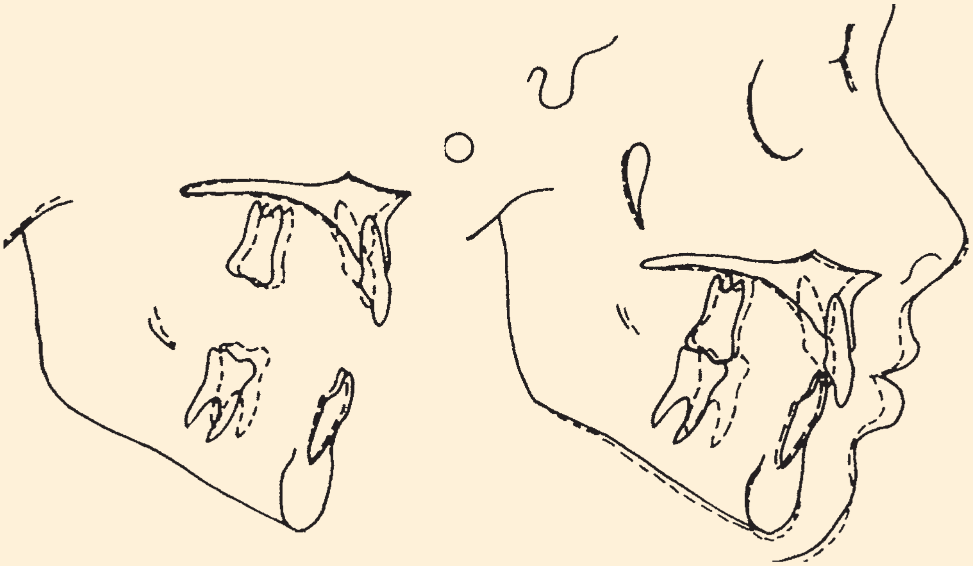


FIGURE 15-57 Pretreatment/posttreatment superimpostitions.

CASE REPORT 15-2

CASE REPORTS: MALOCCLUSION CORRECTION WITH THE EDGEWISE APPLIANCE—cont'd

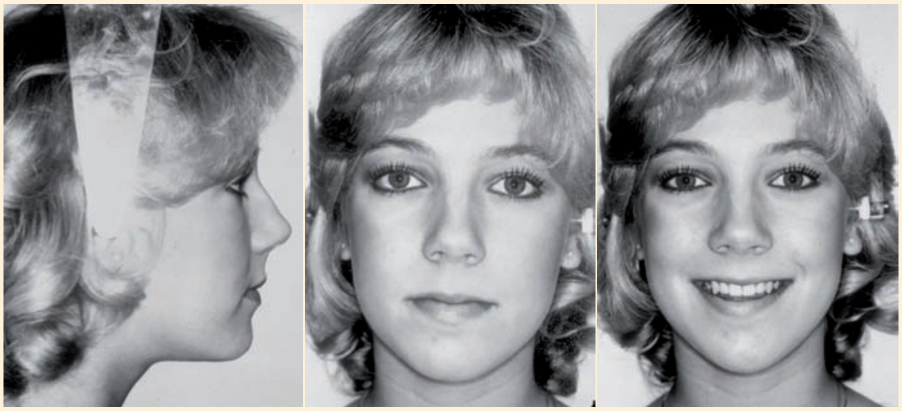


FIGURE 15-58 Ten-year recall facial photographs.

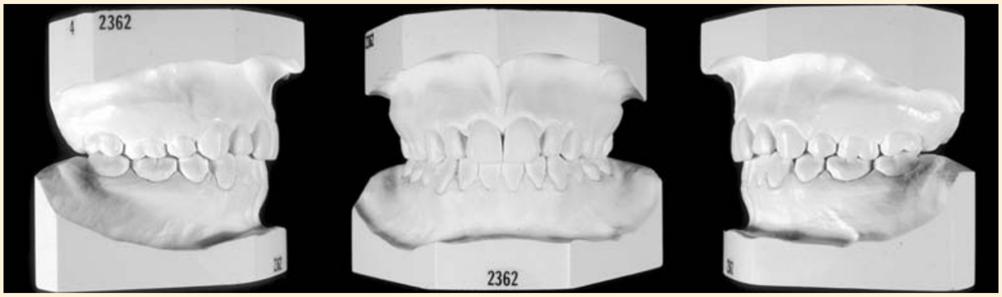


FIGURE 15-59 Ten-year recall casts.

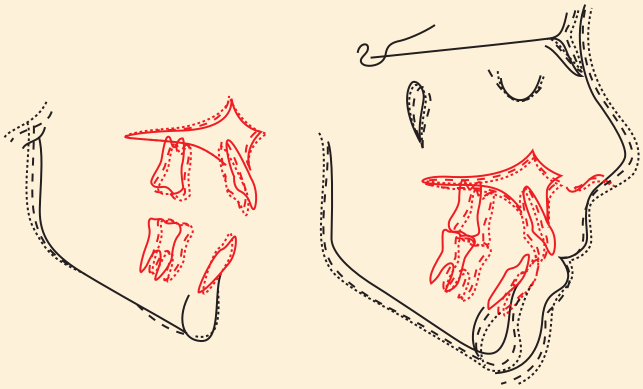


FIGURE 15-60 Ten-year recall superimpositions.

CASE REPORT 15-3 MALOCCLUSION CORRECTION WITH THE EDGEWISE APPLIANCE

Patient: TK

This patient illustrates the correction of an "end-on" Class II, low mandibular plane angle malocclusion that was treated without premolar extractions. The real "secret" to the correction of these malocclusions is control of the mandibular incisors while the maxillary dentition is distalized. The control of the mandibular incisors requires headgear wear to the mandibular arch during leveling and a decision about whether or not mandibular third molars need to be extracted "early" to facilitate mandibular anchorage preparation.

After a careful diagnosis, the treatment plan for many patients requires that their malocclusion be corrected without premolar extraction. It must be kept in mind, however, that if nonpremolar extraction is the treatment plan, third molars have to be carefully evaluated. For many of these patients, the mandibular third molars, in particular, might need to be extracted prior to treatment or at the beginning stages of treatment if the pretreatment positions of these teeth will inhibit mandibular anchorage preparation and/or control of the mandibular dentition. Characteristically, patients whose treatment plan requires nonpremolar extraction for the correction of a Class II malocclusion will have a low mandibular plane angle, mandibular anterior teeth that are "upright" over basal bone, and a mandibular arch that exhibits very mild crowding or no crowding. The records of this patient are shown to illustrate the correction of this type of malocclusion.

The facial photographs (Figure 15-61) illustrate an orthognathic face—but balanced and harmonious soft tissue relationships. The casts (Figure 15-62) exhibit an "end-on" Class II occlusion with a deep vertical overbite, mild mandibular anterior crowding, and a small curve of Spee. The panoramic radiograph (Figure 15-63) confirms the presence of all permanent teeth, but the developing mandibular third molars are not an issue. These teeth are not developing directly under and behind the mandibular second molars. The cephalometric tracing (Figure 15-64) exhibits the low mandibular plane angle, a profile line that is already in the center of the nose, a low ANB, and an FMIA that is a bit "excessive."

The treatment plan dictated that no premolars be removed, that the mandibular arch be leveled, that the teeth be aligned, and that the posterior occlusion be corrected by maxillary dentition distalization and growth. During the denture preparation step of nonpremolar extraction treatment, the archwires are fabricated to begin mandibular terminal molar anchorage and maxillary second molar distalization (Figure 15-65, *A, B*). As these teeth move, more teeth are banded/bonded and the malocclusion is corrected with the sequence of archwires that have been previously described.

The pretreatment/posttreatment photographs (Figure 15-66, *A, B*) confirm maintenance of the balance and the harmony of the face. In fact, the posttreatment photographs exhibit more curvature of the lips than was present at the outset of treatment. The pretreatment/posttreatment casts (Figure 15-67, *A, B*) illustrate correction of the Class II occlusion, as well as maintenance of arch form, arch width, and correction of the deep vertical overbite. The posttreatment panoramic radiograph (Figure 15-68) illustrates the mandibular anchorage, which was not adversely impacted by the development of the third molars. The space between the maxillary first molars and second molars confirms the use of a helical bulbous loop for maxillary molar distalization. The pretreatment/posttreatment cephalometric tracings (Figure 15-69, *A, B*) confirm mandibular incisor control in spite of the

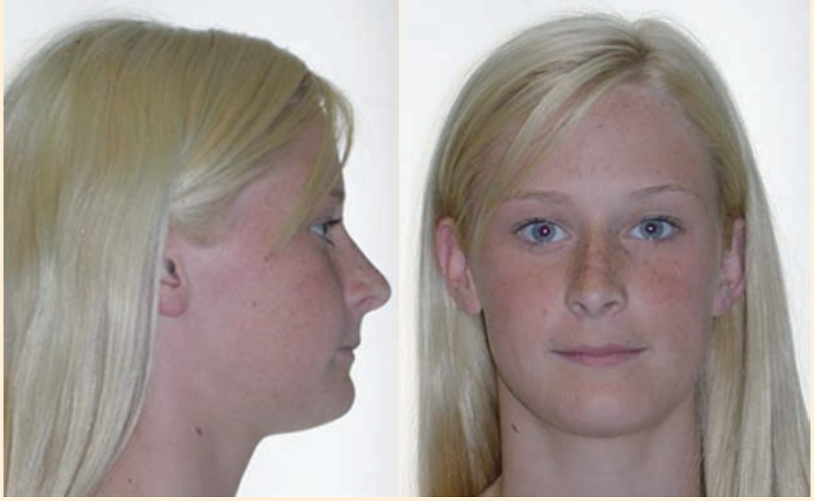


FIGURE 15-61 Pretreatment facial photographs.

CASE REPORT 15-3 **MALOCCLUSION CORRECTION WITH THE EDGEWISE APPLIANCE—cont'd**

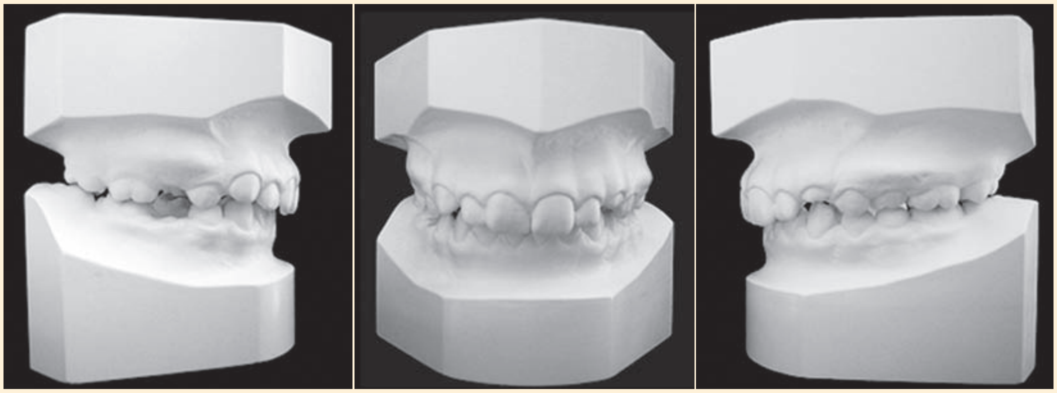


FIGURE 15-62 Pretreatment casts.

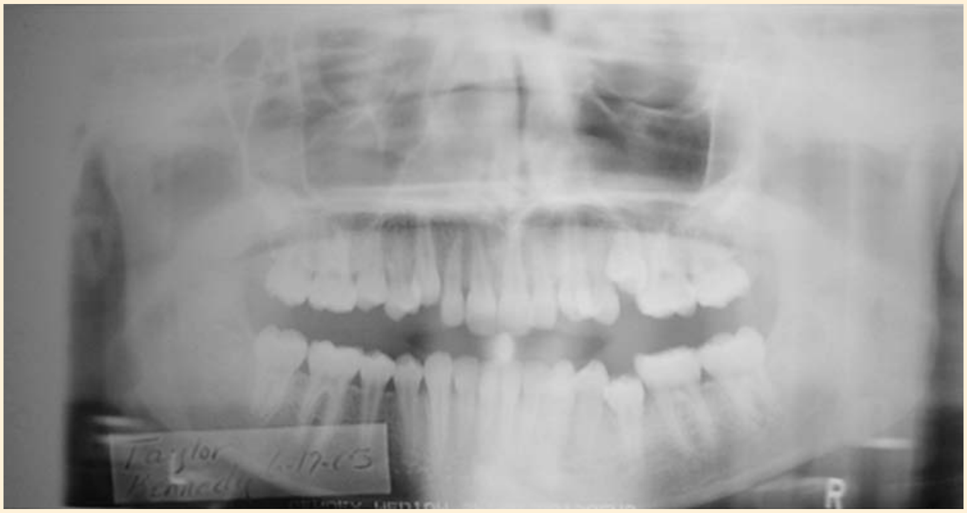
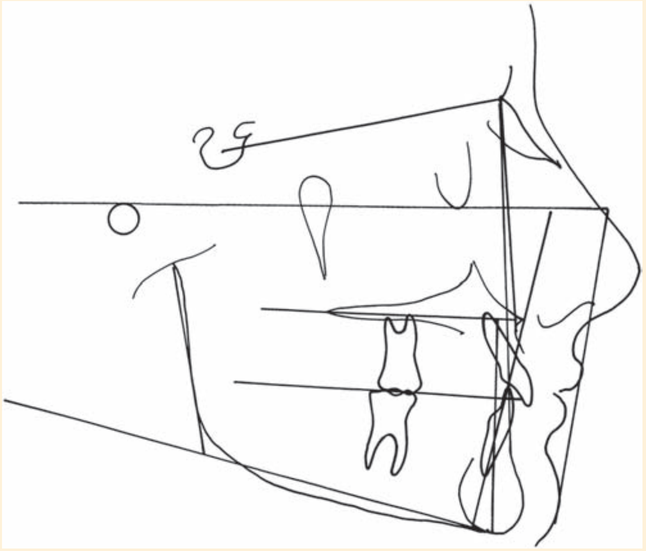


FIGURE 15-63 Pretreatment panoramic radiograph.

Continued

CASE REPORT 15-3 MALOCCLUSION CORRECTION WITH THE EDGEWISE APPLIANCE—cont'd



FMIA	76	OCC	3
FMA	13	Z	82
IMPA	91	UL	14mm
SNA	84	TC	12mm
SNB	81	PFH	50mm
ANB	3	AFH	55mm
AO-BO	1mm	INDEX	.91

FIGURE 15-64 Pretreatment cephalometric tracing.

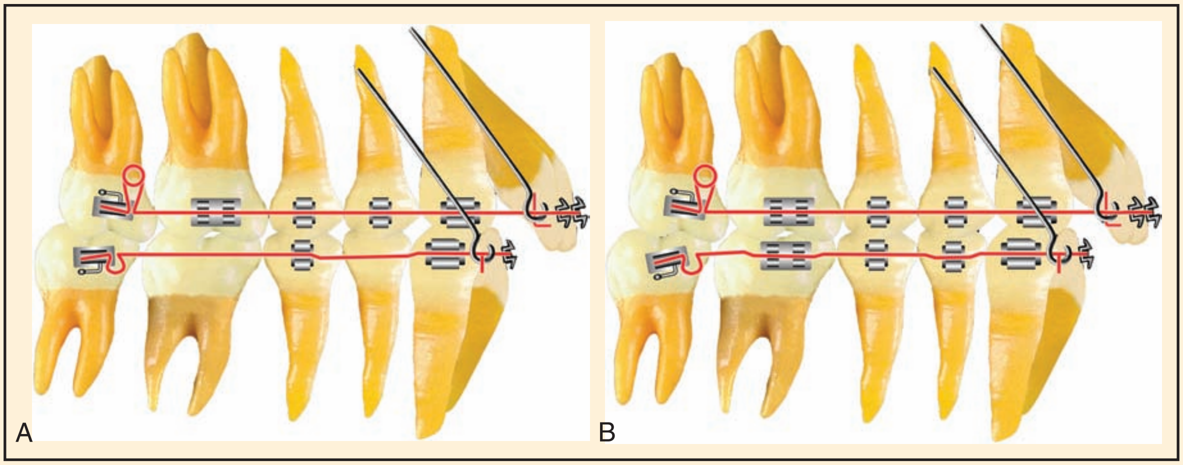


FIGURE 15-65 Denture preparation: nonpremolar extraction. **A,** Initial archwires are designed to begin mandibular terminal molar anchorage preparation and maxillary second molar distalization. **B,** After 1 month the loops are activated more and additional teeth are banded or bonded.

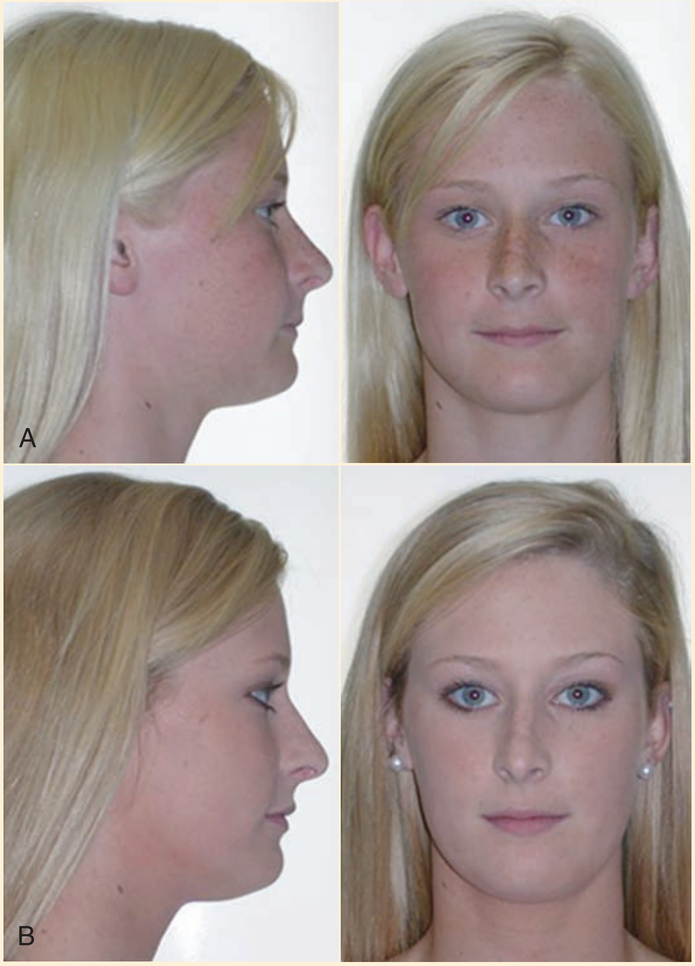


FIGURE 15-66 **A,** Pretreatment and **B,** posttreatment facial photographs.

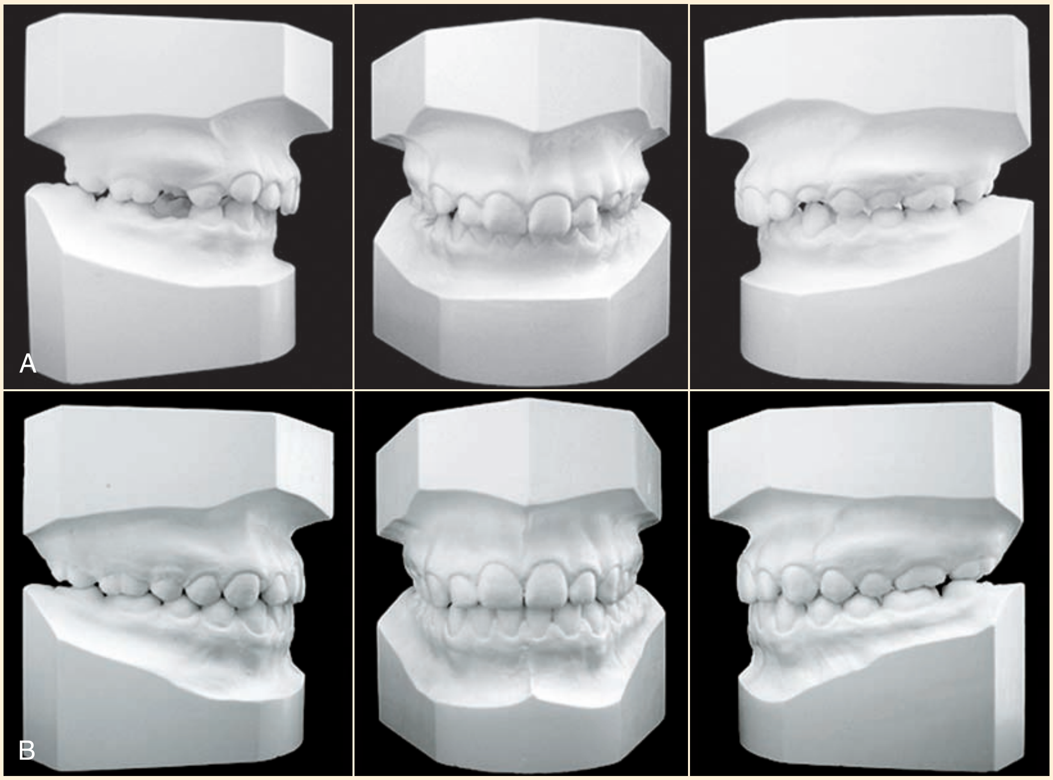


FIGURE 15-67 **A,** Pretreatment and **B,** posttreatment casts.

Continued

CASE REPORT 15-3 **MALOCCLUSION CORRECTION WITH THE EDGEWISE APPLIANCE—cont'd**

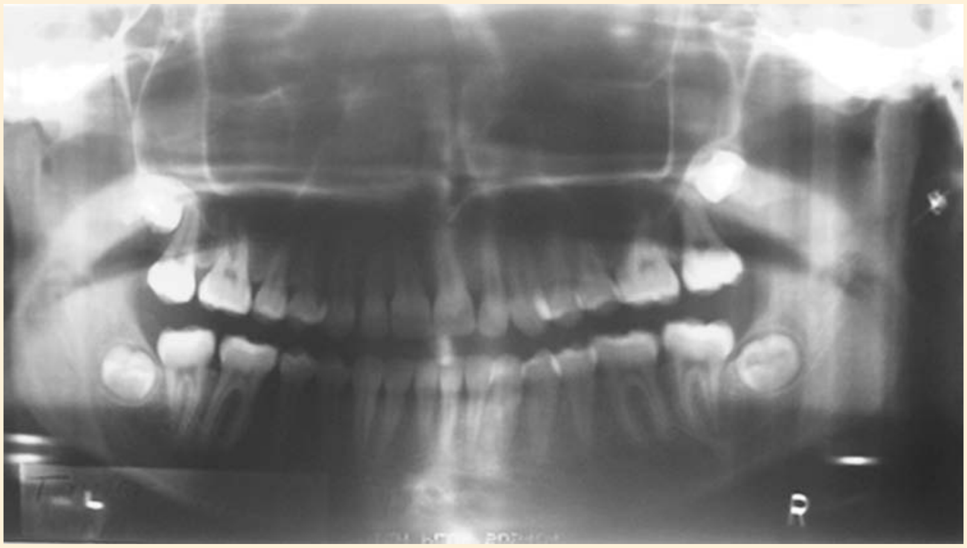
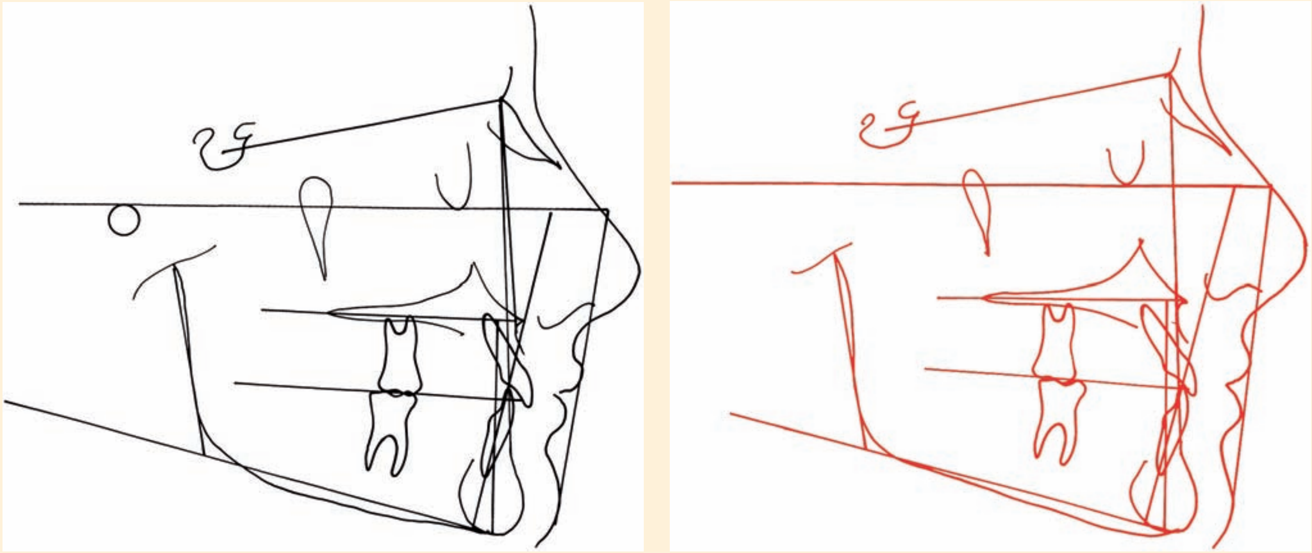


FIGURE 15-68 Posttreatment panoramic radiograph.



A

FMIA	76	OCC	3
FMA	13	Z	82
IMPA	91	UL	14mm
SNA	84	TC	12mm
SNB	81	PFH	50mm
ANB	3	AFH	55mm
AO-BO	1mm	INDEX	.91

B

FMIA	76	OCC	4
FMA	14	Z	84
IMPA	90	UL	15mm
SNA	82	TC	13mm
SNB	82	PFH	53mm
ANB	0	AFH	59mm
AO-BO	−1mm	INDEX	.90

FIGURE 15-69 **A,** Pretreatment and **B,** posttreatment cephalometric tracings.

CASE REPORT 15-3 MALOCCLUSION CORRECTION WITH THE EDGEWISE APPLIANCE—cont'd

use of Class II elastics. The correction of a malocclusion for patients with these problems requires good detention control so that facial balance and harmony are not adversely affected. Pretreatment/posttreatment superimposition tracings of TK (Figure 15-70) confirm a downward and forward change in the relationship of the mandible to the maxilla, vertical molar control and most importantly, control of the mandibular incisors. The correction of the malocclusion was achieved with both tooth movement and favorable growth. An "activity photograph" (Figure 15-71) confirms a very aesthetic smile and a beautiful detention.

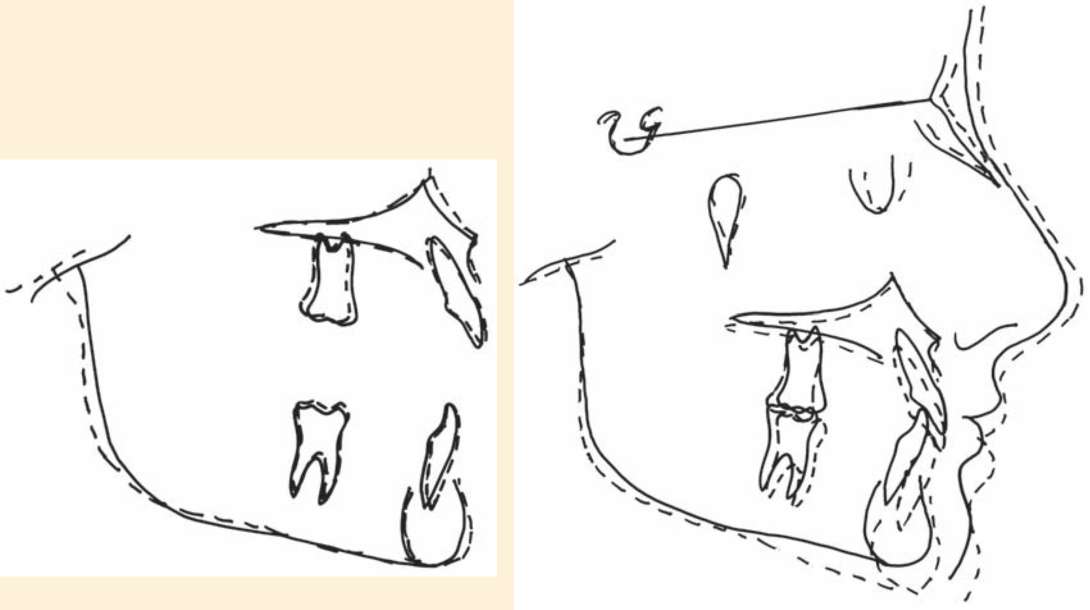


FIGURE 15-70 Pretreatment/posttreatment superimpositions.

FIGURE 15-71 "Activity" photograph.

SUMMARY

The standard edgewise appliance has endured the test of time. Angle was determined to use it to correct malocclusions while preserving the “full complement of teeth.” Angle collaborated with Charles H. Tweed, who, after countless failures, introduced the extraction of four first premolars and anchorage preparation to produce facial balance. The use of the appliance has evolved through many more years with Levern Merrifield, who introduced the following: (1) differential diagnosis, which led to the removal of those teeth that would best produce balance, harmony, and facial proportion within the cranial/facial complex; (2) directional force technology; and (3) sequential wire manipulation. The edgewise appliance is a precise instrument for the routine correction of major malocclusions. Although the Tweed-Merrifield edgewise appliance is the direct descendent of the appliance invented in 1928 by Edward H. Angle, it is used with a totally different philosophy of treatment. A consistent effort is being continuously directed toward its further sophistication. The edgewise appliance has stood the test of time and will be used by many more generations of orthodontists.

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CHAPTER

16

Contemporary Treatment Mechanics Using the Straight Wire Appliance

Antonino G. Secchi, Jorge Ayala

"It is not only the appliance system you have, but how you use it ..."

OUTLINE

Straight Wire Appliance Design and Values
Straight Wire Appliance and Self-Ligation
Optimal Bracket Placement
Treatment Mechanics
  Stage 1: Leveling and Aligning
  Stage 2: Working Stage
  Stage 3: Finishing Stage
Summary

The straight wire appliance (SWA) was developed and introduced by Lawrence Andrews in 1970[1] with the idea of having an orthodontic fixed appliance that would enable the orthodontist to achieve the "Six Keys" of normal occlusion[2] in the vast majority of cases in an efficient and reliable fashion.

Even though the SWA is 40 years old and has become the most common appliance concept over the past three decades, a review of some of the original concepts on which the SWA was designed and the evolution it has gone through are fundamental to better understand the beauty of this appliance and the treatment mechanics, which we then discuss.

STRAIGHT WIRE APPLIANCE DESIGN AND VALUES

There are few features that need to be present in an appliance to be considered a true SWA.[3] First, each bracket has to be tooth specific and have built-in torque, tip, in/out, and, for the molars, the proper offset. Second, the torque has to be built in the base of the bracket, not in the face, and the tip in the face of the slot. These prerequisites are very important in order to achieve proper alignment of the center of the slot, the center of the base, and the reference point (middle of the clinical crown occlusogingivally along the facial long axis of the crown) for all teeth at the completion of treatment. This is the only way that the desired built-in features can be properly transferred from the bracket to the tooth. Third, the base of the bracket must be contoured mesiodistally and occlusogingivally. This has been referred to as "compound contour" base, and it allows the bracket to firmly adapt to the convexities of the labial surface of each tooth, helping the orthodontist to achieve an optimal bracket placement.

Although Andrews thought his appliance could be used to treat a large variety of cases, he introduced a series of additional brackets with different degrees of overcorrection to account for undesired tooth movement that would occur specifically when sliding teeth in extraction cases. For example, if a maxillary canine had to be moved distally, because Andrews uses round stainless steel wires to slide teeth through, the canine most likely would tip and rotate distally. Therefore, he introduced more mesial tip and rotation to the canine bracket. Andrews then came out with a line of overcorrected brackets, which he called first Extraction Brackets[3] and then Translation Brackets.[5] Andrews' complete bracket system (Standard and Translation Brackets) became less popular than expected, in part due to the large bracket inventory needed to satisfy his treatment mechanics. However, in the mid 1970s, Ronald H. Roth took Andrews SWA and combined some of the Standard

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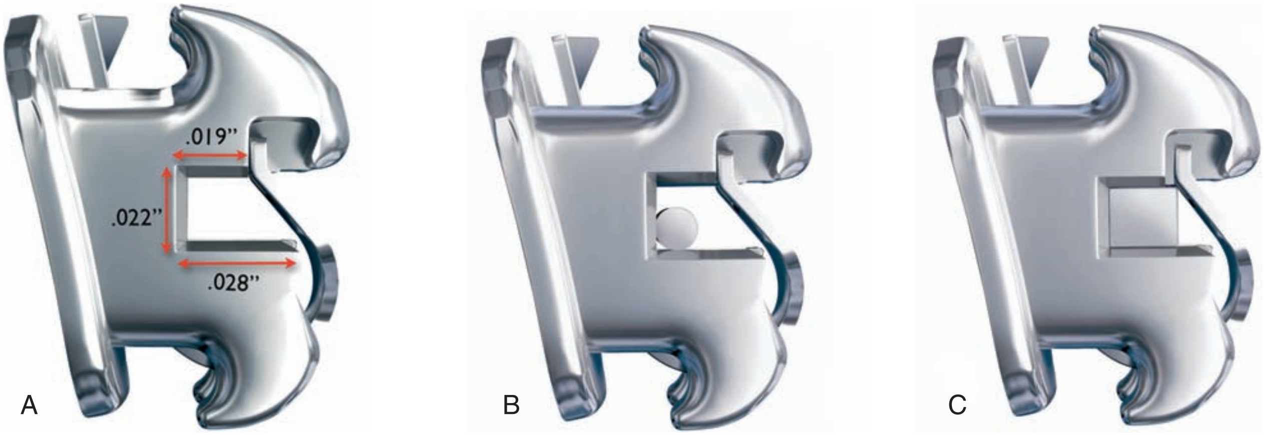

FIGURE 16-1 This figure shows the design features that make a self-ligating bracket to be active. **A,** Notice the difference in the depth of the occlusal wall of the slot compared with the gingival wall. **B,** This particular active SLB (In-Ovation R) wire is smaller than 0.019 inch; the clip is not active. **C,** A wire bigger than 0.019 inch pushes out the clip and therefore aviates it.

Bracket prescription values with some of the overcorrected values found in the Translation Bracket prescription to create the "Roth setup."[6] The Roth prescription became the most popular SWA prescription in the world. Roth realized that because the size of the brackets at that time caused bracket interferences, it was virtually impossible to place each tooth in its final ideal position. Also, he observed that when appliances were removed, teeth would rebound and settle. Therefore, he slightly overcorrected some of the original Andrews values to allow teeth to properly settle in the ideal final position after removal of the appliances. After the Roth prescription, a great number of clinician came out with small variations to either the Andrews prescription or the Roth prescription. Most of these changes were done either for a commercial purpose, to compensate for unknown errors in bracket position or to suit a particular orthodontist's type of mechanic.

Today, there are a large number of preadjusted appliances wrongly called SWA only because they have built-in torque, tip, and in/out. However, if they are not manufactured with the features specified earlier, the appliance will not transfer the built-in information correctly to the teeth. Therefore, selecting the proper appliance is paramount when using an SWA.

STRAIGHT WIRE APPLIANCE AND SELF-LIGATION

Both of the authors of this chapter use a self-ligating bracket (SLB) system and, consequently, some of the concepts on mechanics that will be reviewed later take advantage of such appliance systems. Therefore, even though self-ligation is the subject of Chapter 17 in this book and thus is extensively reviewed, it is important to point out a few aspects of this type of appliance that will allow the reader to better understand the information provided in this chapter.

SLBs have been classified as "active" or "passive" depending on the behavior of the gate or clip on the archwire. Active SLBs have a clip with a spring effect that exerts pressure on the archwire, pushing it onto the base of the bracket's slot. This pressure is based on the archwire size and/or bracket/archwire configuration (Figure 16-1). On the other hand, passive SLBs have a gate that passively opens and closes without exerting pressure on the archwire. Passive SLBs also have been described as tubes.[7] We believe active SLBs have some important advantages over passive SLBs. In active SLBs, as we stated earlier, one can manage the amount of "activity" that the clip will have by the size of the archwire. For instance, at the beginning of treatment when less resistance to sliding is desirable and usually the archwire of choice is a small, round thermal-activated wire, both active and passive brackets have shown equal behavior.[8] As treatment progresses, an increased resistance to sliding is desired to achieve proper torque expression. At this stage of treatment, passive SLBs have demonstrated poor behavior compared with active SLBs.[9,10] It is important to remember that the active clip is just a very nice feature of certain brackets; not every active available SLB is an SWA. The SLB must have all the other features mentioned earlier to be a true SWA.

Optimal Bracket Placement

Assuming we have the right appliance, the next most important factor when working with an SWA is bracket position. Here is where the orthodontist's dexterity will be of great value. As with techniques that require bending the wire, the quality and precision of each bend will determine to some extent the quality of the final result, the precision of bracket placement will do it when using an SWA. When using an SWA, you "start finishing" your case the day you place the brackets. This is why an important percentage of problems that orthodontists

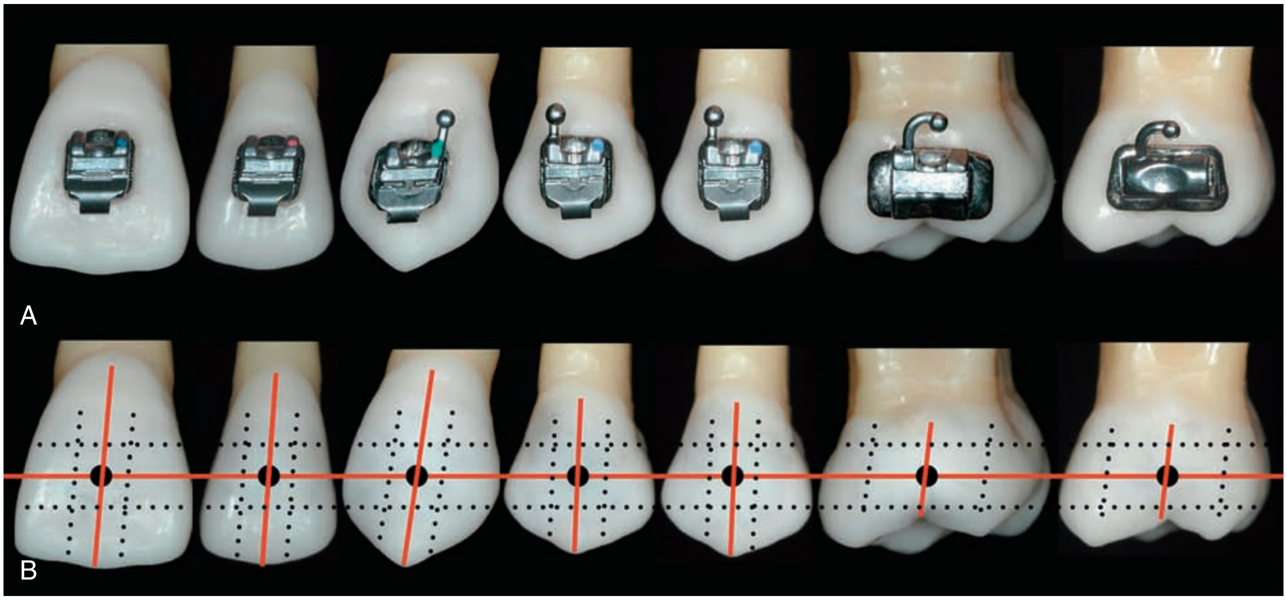

FIGURE 16-2 All the brackets aligned along the references described by Andrews such as the FA point and the long axis of the clinical crowns. In **B,** the long axis of the clinical crown for the molars is the buccal groove.

experience toward the end of active treatment—such as marginal ridge discrepancies, difficulty correcting rotations, lack or root parallelism, and, ultimately, less than ideal tooth position—are due to incorrect bracket placement. As Andrews described 40 years ago that the brackets should be placed at the FA point. The FA point is the middle of the clinical crown occlusogingivally and mesiodistally, following the long axis of the crown, for each tooth in the mouth (Figure 16-2).

Because all the brackets are working at the same time through the wire, one misplaced bracket will automatically affect the adjacent brackets. If more than one bracket is misplaced, the problem will increase and become more noticeable as the wire sequence progresses. This issue, if not corrected, can prevent the orthodontist from finishing the case in an optimal and efficient way.

Because we have a limited space in this chapter, we will not describe the specific bracket position for each individual tooth but rather focus on the teeth that usually cause more problems for clinicians. Then, it is important to emphasize the following concepts:

- Andrews demonstrated that trained clinicians are able to place brackets consistently at the FA point without any aids but their own eyes.
- The use of any gauge as an aid to position the brackets it is not necessary; in fact, to use any predetermined height from the incisal edge to locate the brackets, as some orthodontists advocate, is wrong and negates the use of the FA point, which is one of the fundamentals of the proper management of the SWA. However, you have to take into account shorter crowns due to excessive gingival tissue, worn teeth, and/or fractured teeth that eventually will be restored, so in some of these situations, the brackets will look more incisally or gingivally than they should be.
- To fully level and express the torque, tip, and in/out of each bracket, the slot of the bracket has to be filled, which requires 0.021- × 0.025-inch stainless steel wire. It is important to know that a 0.019- × 0.025-inch stainless steel wire has about 10.5 degrees of play on a 0.022-inch bracket slot.[11] However, this is not the case when using active SLBs, as we explain later in the chapter.

Although the FA point and long axis of clinical crowns are key to bracket position, there are a few specific considerations that will facilitate bracket placement on certain teeth, such as the upper and lower canines, upper and lower first molars, and sometimes upper lateral incisors and premolars.

- **Canines:** The long axis of the upper and lower canines, which is also the most convex part of the labial surface, is located more mesial than the true mesiodistal center of the tooth; therefore the FA point looks a little bit more mesial than the dead center of the tooth. If you err and place the bracket on the center of the crown mesiodistally, the canine will rotate mesially.
- **Molars:** The landmark that Andrews used as the long axis of the clinical crown for the molar is the buccal groove. The FA point then lies along the buccal groove, midway occlusogingivally (see Figure 16-2). It is important to realize that the center of the tube mesiodistally should be in agreement with the FA point. As some manufacturers have reduced the mesiodistal length of tubes, orthodontists have started

positioning tubes too far mesial with the consequential distal overrotation of the molars.

- **Upper lateral incisor**: After the third molars, upper lateral incisors are the teeth with problems regarding size and shape. This makes it difficult to determine the long axis of the crown from the buccal. It is wise to use the mirror to look at the lingual surface of the incisor and then extend the long axis of the clinical crown from the lingual to the buccal.
- **Premolars**: Usually premolars, specifically second premolars, represent a challenge at the time of bonding due to lack of direct vision. Then it is advisable to look with the mirror from the occlusal and the buccal to locate the FA point and the long axis of the clinical crown.

Treatment Mechanics

For didactic purposes, treatment mechanics usually has been usually divided in different stages, from three to seven depending on authors' preference. Simplicity is of paramount importance when teaching, and therefore, all the mechanics to be accomplished in our orthodontic treatments with the SWA can be divided into three stages: stage 1, leveling and alignment; stage 2, working stage; and stage 3, finishing stage.

At each of these stages, there are specific movements of teeth that will occur and specific goals that have to be achieved before continuing to the next stage of treatment. It is important to emphasize that both the treatment outcome and its efficiency will be greatly improved if the orthodontist follows these stages. The following stages of treatment mechanics, with their respective wire sequence, have been tailored for active SLBs, although they can be applied to any SWA.

Stage 1: Leveling and Aligning. Leveling and aligning is a complex process in which all the crowns are moving at the same time and in different directions. As the teeth level and align, reciprocal forces between them develop, which can be of great help to guide the movements to our advantage. Then, when possible, all teeth should be engaged from the beginning to obtain maximum efficiency of tooth movement. Usually at this stage, round small-diameter thermal-activated wires such as a 0.014-inch Sentalloy for severe crowding or an 0.018-inch Sentalloy for moderate to minimum crowding are preferred. In cases that required retraction of the incisors it is recommended to cinch the wire back of the second molar tube or to place crimpable stops to avoid undesirable movement of the wire, causing discomfort to the patient. These round wires can be in place for as long as 8 to 12 weeks before proceeding to the next wire, which usually is a 0.020- × 0.020-inch Bioforce. The Bioforce wire is a low-deflection thermal-activated wire that works very well as a transitional wire from stage 1 to stage 2. The 0.020- × 0.020-inch Bioforce corrects most of the rotations left by the previously used round wires and provides more stiffness to start leveling the curve of Spee and therefore flatten the occlusal plane. It is important to notice that even if you could start treatment with a rectangular or square thermal-activated low-deflection wire, with the assumption of saving time and providing torque from the beginning of treatment, this is absolutely not recommended, because it may cause loss of posterior anchorage. This happens for two main reasons: first, the only teeth with positive labial crown torque are the maxillary central and lateral incisors, and second, the mesial crown tip of the maxillary and mandibular canines is rather large. Therefore, if we start treatment resolving the crowding with a rectangular or square wire, we are providing labial crown torque to the maxillary incisors and mesial crown tip to canines, which will increase our anchorage in the front part of the arch facilitating the loss of anchorage in the posterior part of the arch. This is critical in cases where the treatment plan calls for maximum retraction of the maxillary and/or mandibular incisors. In these particular cases, the use of a 0.020-inch Sentalloy or stainless steel wire can be better indicated than the 0.020- × 0.020-inch Bioforce and thus it will not provide torque and the tip effect on the canines will be minimal. This will allow the molar and premolars to level, align, and upright, which will produce a "lasso" effect on the incisors that will upright and sometimes even retract them (Figure 16-3).

The 0.020- × 0.020-inch Bioforce will make the clip of the SLB active and thus start delivering torque; nonetheless, its strength is not sufficient to compromise the anchorage that has already been created with the round wires. Usually, after 8 to 10 weeks with the 0.020- × 0.020-inch Bioforce, the stage 1 of leveling and aligning is finished and in the authors' opinion it is the first time to evaluate bracket placement and debond/rebond as necessary. Then we are ready to start stage 2, the working stage.

The following are the movements we should expect and goals we should accomplish when leveling and aligning, before starting Stage 2:

- Teeth move individually.
- It is mainly crown movement.
- Molars and Pm derotate and upright distally.
- Incisors are upright and sometimes even retract.
- Start building posterior anchorage.
- Before proceeding to stage 2, check bracket position (gross errors) and debond/rebond as indicated.

The following are the most common wires and sequence used at stage 1 of treatment:

- Mainly round, small-diameter, superelastic wires (ideal thermal activated)
- Square or rectangular superelastic wires to correct remaining rotations and level the occlusal plane (Tables 16-1 and 16-2)

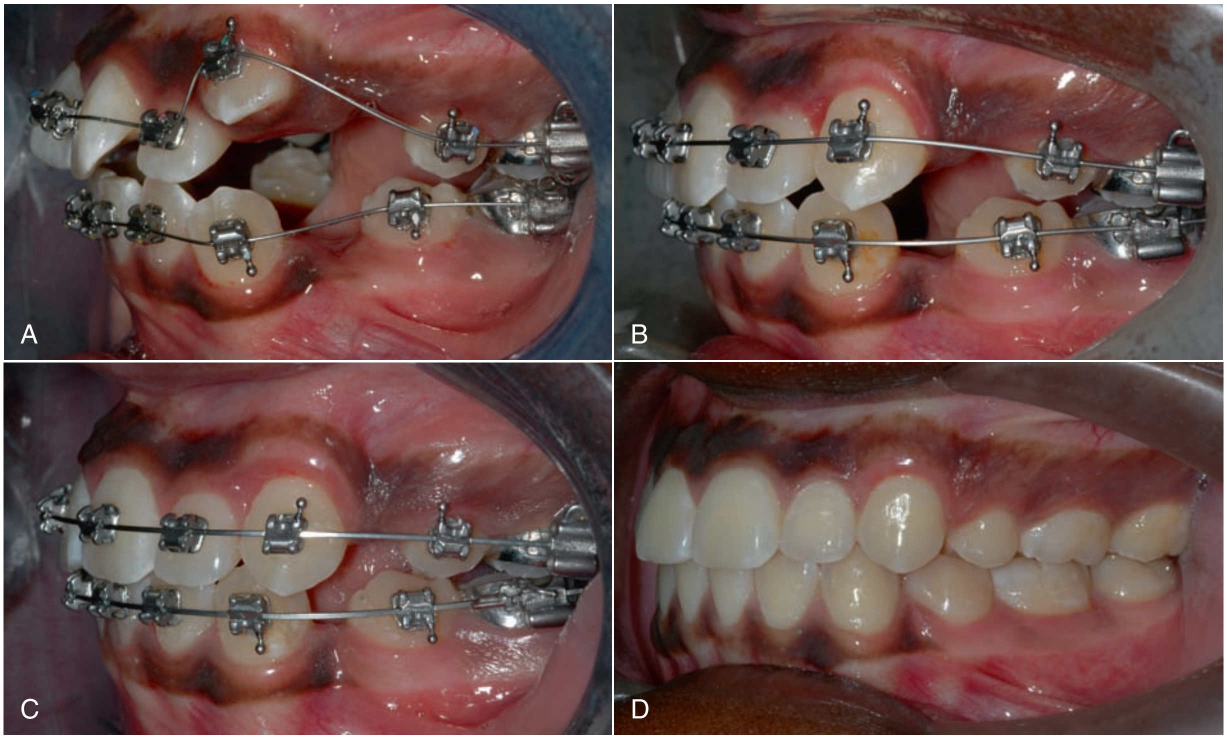

FIGURE 16-3 As the initial alignment occurs, molars upright and the maxillary and mandibular planes of occlusion become more parallel, helping to retract the incisors and improve the overbite. The wire sequence is very important to control tip, torque, and rotations. Small, round Sentalloy wires such as 0.014 **(A)** and 0.018 **(B)** inch are excellent to control initial alignment; upright incisors, premolars, and molars; and correct major rotations. Bioforce wires such as 0.020- × 0.020-inch **(C)** are ideal to finish with the leveling and aligning stage. This wire will finish correcting the rotations still present after the round wires. It will also express more crown tipping and will start providing a small amount of torque because its dimension will mildly activate the springing clip of the bracket. **D,** Finished case.

TABLE 16-1 Types of Wires, Size, and Sequence Suggested for Stage 1 of Treatment Mechanics, in Cases with Moderate to Severe Crowding

STM1 Type	Severe to Moderate Crowding	
	Size (inches)	**Sequence**
Sentalloy	0.014	0.014
	0.018	
Bioforce	0.018 × 0.018	0.018
	0.020 × 0.020	
	0.019 × 0.025	0.020 × 0.020

Sentalloy and Bioforce are trademarked brands of GAC International, Bohemia, NY.

TABLE 16-2 Types of Wires, Size, and Sequence Suggested for Stage 1 of Treatment Mechanics, in Cases with Mild Crowding

STM1 Type	Mild Crowding	
	Size (inches)	**Sequence**
Sentalloy	0.014	0.018
	0.018	
BioForce	0.018 × 0.018	0.020 × 0.020
	0.020 × 0.020	
	0.019 × 0.025	

Sentalloy and Bioforce are trademarked brands of GAC International, Bohemia, NY.

Stage 2: Working Stage. This stage of treatment is the one on which we will spend more time. At this stage, the maxillary and mandibular arches are coordinated, proper overbite and overjet are achieved, Class II or Class III are corrected, maxillary and mandibular midlines are aligned, extraction spaces are closed, and maxillary and mandibular occlusal planes are paralleled. Although most of these corrections happen simultaneously, we will describe them separately for didactic reasons so key points can be emphasized.

Arch Coordination. The maxillary and mandibular archwires must be coordinated in order to obtain a stable occlusal intercuspation and proper overjet. In an ideal intercuspation of a Class I, one-tooth to two-teeth occlusal scheme, the palatal cusps of the maxillary molars should intercuspate with the fossae and marginal ridges of mandibular molars, the buccal cusp of the mandibular premolars should intercuspate with the marginal ridges of the maxillary premolars, and the mandibular canines and incisors should intercuspate with marginal ridges of the maxillary canines and incisors. If this occlusal scheme occurs, it will then provide an overjet of 2 to 3 mm all around the arch from second molar to second molar. Then, the maxillary archwire must be 2 to 3 mm wider than the mandibular archwire. The archwire coordination is done with the stainless steel wire. Even if they come preformed, the clinician should not rely on it and check them before insertion. Another important aspect of arch coordination is the effect that it has on the vertical dimension and the sagittal dimension. Arch coordination is a transverse issue. The maxillary teeth should be upright and centered in the alveolar/basal bone and coordinated with the mandibular teeth, which should also be upright and centered in the alveolar/basal bone to obtain a proper intercuspation. Often, this is not the case and we find maxillary molars buccally inclined, also referred as an accentuated curve of Wilson, which can produce contacts between the palatal cusp of maxillary molars and the inclines of the mandibular molars. This decreases the overbite and sometimes produces even an openbite (vertical problem), which in turn can produce a downward and backward movement of the mandible (sagittal problem). This phenomenon is due to the lack of palatal crown torque of the maxillary molars. Depending on the amount of palatal crown torque needed for the maxillary molars to level the curve of Wilson, we suggest three solutions:

1. For minor problems with torque, we can wait until the finishing stage where a larger size wire (0.021- × 0.025-inch stainless steel) can be used to fill the slot and deliver more torque to the molars.
2. For moderate problems with torque, we can add palatal crown torque to the working wire.
3. For severe problems with torque, the use of a transpalatal bar (TPB) is suggested. TPB can be used to easily place and deliver palatal crown torque to maxillary molars (Figure 16-4).

Overbite and Overjet Correction. An optimal overbite/overjet relationship does not have to be a certain predetermined number of millimeters. More important is the functional relationship they have. This means that the overbite/overjet should be compatible with a mutually protected occlusal scheme and thus allows for a proper anterior guidance in protrusion and lateral excursive movements. Although, as we said, the number of millimeters is less important than the function, we find that an optimal overbite is usually around 4 mm and an optimal overjet is 2 to 3 mm. When diagnosing and treatment planning overbite/overjet problems, it is important to take the following key points into consideration: arch space management, position of the mandible in centric relation, and relationship of the upper/lower incisors with the lips. Arch space management is important to understand because the SWA tends to flatten the curve of Spee, which requires space in the arch. If not enough space is available or created, the incisors will procline, increasing the arch perimeter. This incisor proclination will also decrease the overbite and may help, if it only occurs in the lower arch, to decrease the overjet. Flattening the maxillary and mandibular occlusal planes proclining the incisors can be of help in deep bite cases (Figure 16-5). When the incisors are not allowed to procline, space in the arch must be created. This is specifically important to avoid periodontal problems in cases with thin bone surrounding the incisor area. Advanced diagnostic imaging tools such as the CBCT could be of great help to precisely identify the

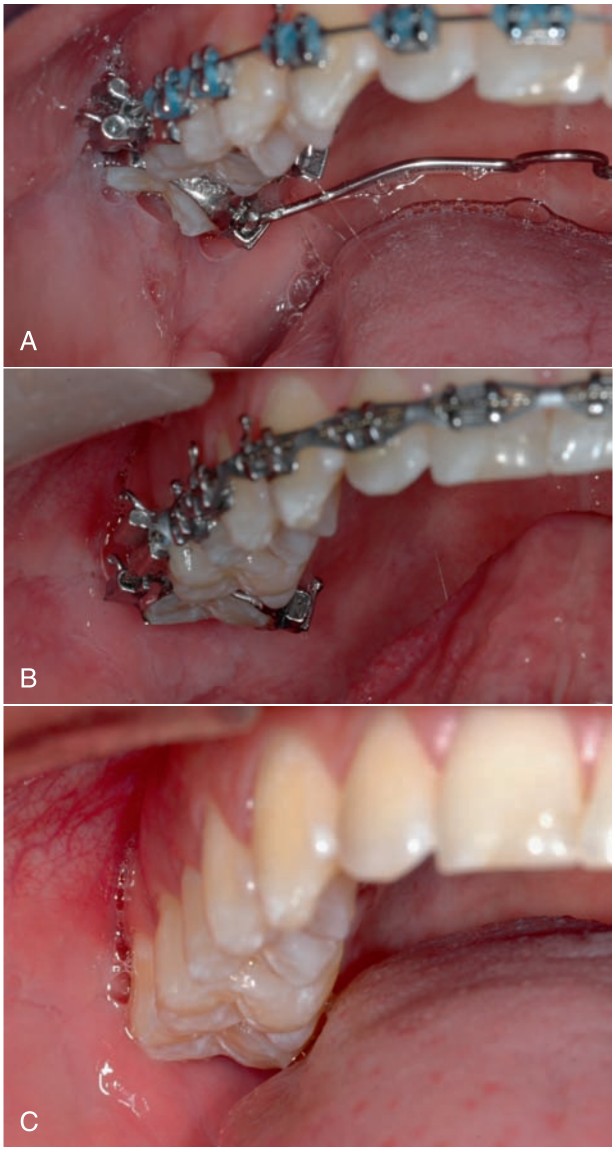

FIGURE 16-4 Shows a sequence of a maxillary second molar severely tipped to the buccal corrected with a transpalatal bar. **A,** Initial. **B,** After correction is done. **C,** Finished case.

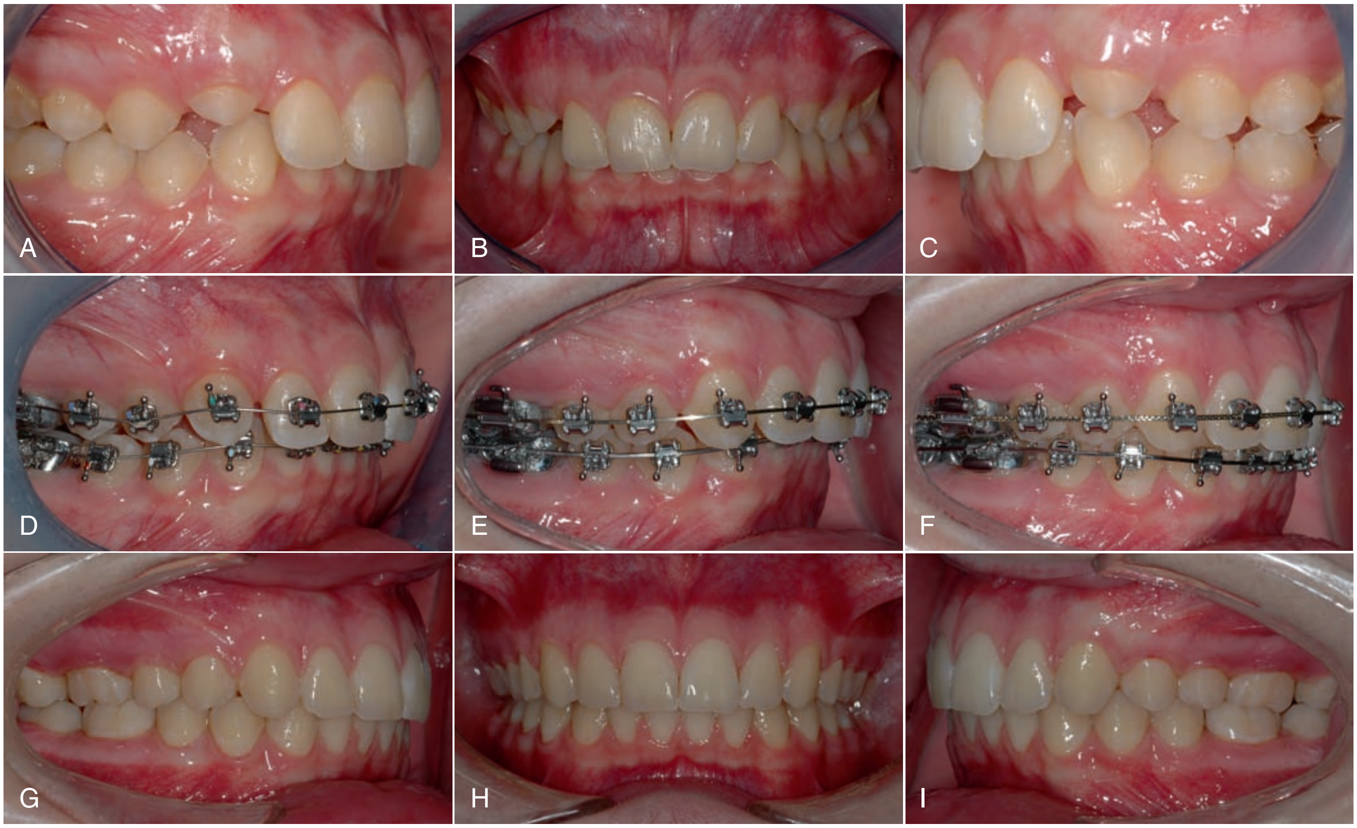

FIGURE 16-5 Shows a deep bite case where the occlusal plane was flattened with the use of a reverse curve of Spee on a 0.019- × 0.025-inch stainless steel wire. **A–C,** Initial intraoral views. **D**, Initial wire to level and align. **E,** A 0.019- × 0.025-inch stainless steel wire with reverse curve of Spee before correction. **F,** A 0.019- × 0.025-inch stainless steel wire with reverse curve of Spee after correction. **G–I,** Final intraoral views.

condition of the bone in this area. Up to 4 to 6 mm can be created with interproximal reduction of teeth, usually done on the incisors and, less often, the canines and premolars. If more than 6 mm of space is required, extraction of premolars could be indicated. Another important factor to consider when evaluating overbite/overjet problems is the position of the mandible. Often, differences between a maximum intercuspation (MIC) and centric relation (CR) can produce significant differences in the overbite/overjet relationship. This can be clearly seen in Figure 16-6, where what looks like a normal overbite/overjet relationship in MIC is an anterior openbite in CR. In this case, as the mandible rotates close in CR, a primary contact found at the second molar keeps the bite open in the anterior, decreasing the overbite and preventing the mandible to achieve a more stable occlusal scheme. At last, but by no means the least important, is the sagittal and vertical relationship of the maxillary and mandibular incisors with the lips. In an openbite case, should we intrude the molars or extrude the incisors? In a deep bite case, should we intrude the maxillary incisors, the lower, or both? These basic but very important questions can be answered through an understanding of the optimal relationship of the incisors with the lips. According to contemporary aesthetic trends and taking into account the aging process, for adolescents and young adults, maxillary incisors should have, at rest, an exposure of about 4 mm beyond the most inferior point of the upper lip known as upper stomion. As explained earlier, an optimal functional overbite should be about 4 mm. Now, if we put together the last two concepts, the incisal edge of the lower incisors should be at the same level with the most inferior point of the upper lip. Therefore, any vertical change of the incisors will affect not only the function through changes of the anterior guidance, but also the aesthetics through the amount of tooth exposure. These anterior functional/aesthetic references explained by Ayala as the "upper stomion concept" will help the clinician to determine the best strategies to correct overbite/overjet problems and will be of special importance for planning cases involving orthognathic surgery.

Closing Extraction Spaces. Usually after leveling and aligning, the extraction spaces left are smaller than at the beginning of treatment because some of the space has been taken to unravel the initial crowding and to upright the maxillary and mandibular incisors, as described earlier on this chapter. Also, the maxillary and mandibular occlusal planes should be flat or almost flat, and the six anterior teeth should be consolidated into one unit. Then, to efficiently close the remaining spaces, achieving the desired functional and aesthetic goals, we

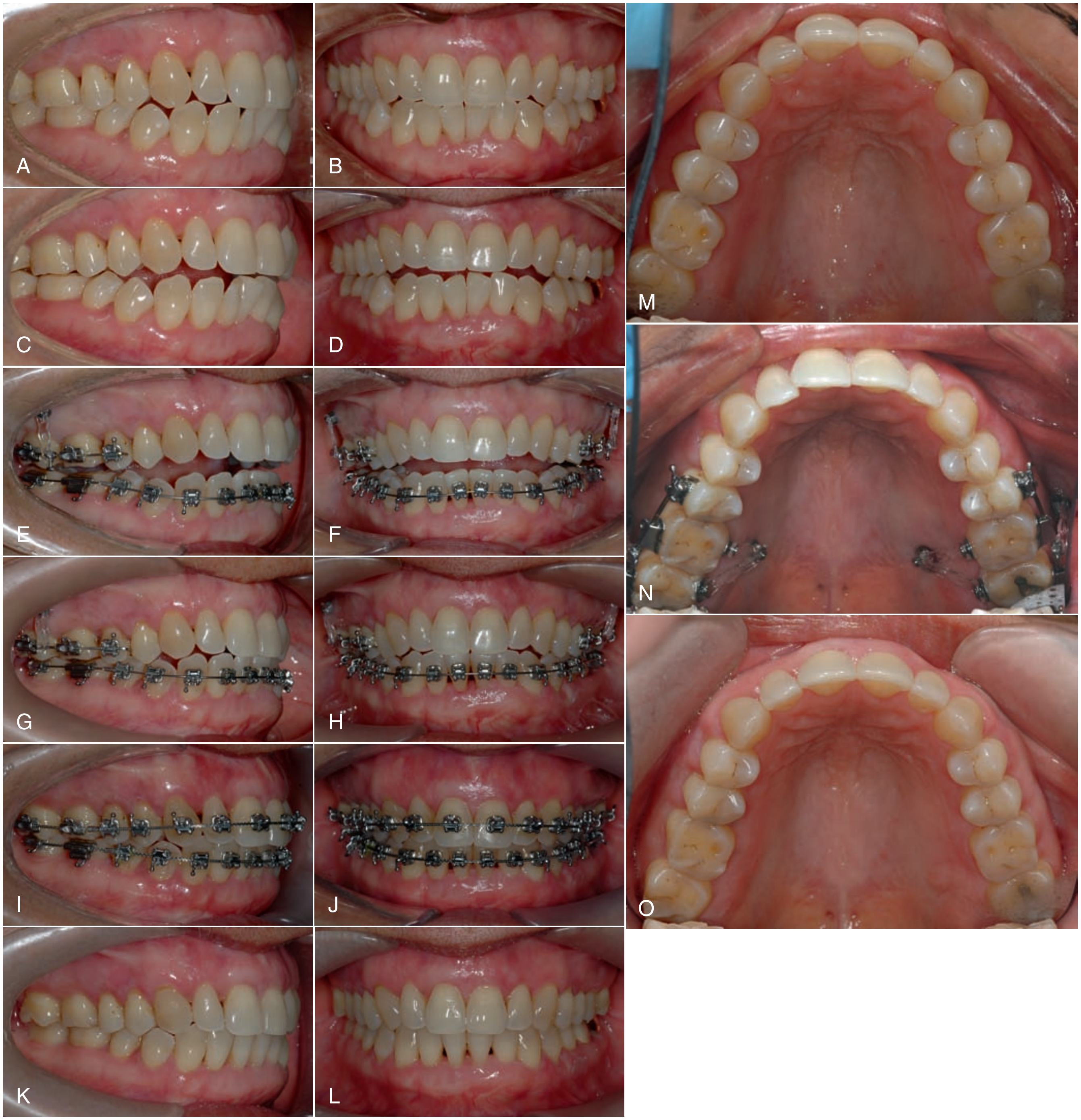

FIGURE 16-6 An example of a case with a clinical significant discrepancy between a maximum intercuspation (MIC) and centric relation (CR). This case was treated with the aid of mini-implants to control the vertical position of the maxillary first and second molars. **A, B,** Initial intraoral views in MIC. **C, D,** Initial intraoral views in CR. **E, F,** Intraoral view before molar intrusion. **G, H,** Intraoral view after molars have been intruded and openbite closed. **I, J,** Intraoral view with final wire. **K, L,** Intraoral view after appliances have been removed. **M–O,** Occlusal intraoral views of the maxillary arch before treatment, during treatment with mini-implant, and after treatment.

need to determine the anchorage requirement. This will allow us to know which teeth should be moved more mesially or distally and therefore to choose the appropriate mechanics. We believe that one of the easiest ways to determine the anchorage requirement is to perform a visual treatment objective (VTO). The VTO is a cephalometric exercise in which we modify the patient's cephalometric tracing to achieve the desired "end of treatment" result and then, by superimposing both tracings, we can visualize the movements that need to occur to obtain that result. The VTO is not a formula or equation that will determine or impose a specific type of treatment, but rather an exercise in which we take into account our experience gathered from other similar cases, an estimation of the growth the patient will have during treatment, the patient's biotype and soft tissue characteristic, and so on to more accurately treatment plan our cases and have a visual representation of it. Thus, after the VTO has been performed, the anchorage requirement can be minimum, medium, or maximum. Before describing each one of these anchorage situations, it is important to indicate the wires and auxiliaries used at this stage. In our mechanics, we use either a double keyhole loop (DKH) or a straight wire with hooks and Sentalloy coils (Sentalloy is a trademarked brand of GAC International, Bohemia, NY). Both of these types of wires are stainless steel and can be either 0.019- × 0.025-inch or 0.021- × 0.025-inch, depending on the anchorage situation. The Sentalloy coils can be light (100 g), medium (150 g), or heavy (200 g). Also, when the anchorage situation calls for it, we use TPBs and temporary anchorage devices (TADs).

DKH Activation. The DKH archwire can be activated in two different ways. It can be pulled from the distal of the first or second molar, so as to open the loops 1 mm, and then cinched back to keep the loops open. As the loops close, the teeth come together, closing the space. A different activation method is to open the loops 1 mm and then use a stainless steel ligature to ligate the distal loop to the hook of the first or second molar tube, with sufficient tension to keep the loops open. As the loops tend to close, the ligature will exert force on the molar tube and the teeth will come together. In either way of activation, changes in wire size and place of activation will determine the type of anchorage obtained.

Sentalloy Coil Activation. Sentalloy coils come in three different strengths: 100 g (blue dot), 150 g (yellow dot), and 200 g (red dot). It is the authors' preference to use the 150 g Sentalloy coil. These coils deliver the same force independent of the amount of activation. In our mechanics, we usually crimp a surgical type of hook distal of the canine from which a Sentalloy coil is engaged all the way to the hook of either the first or second molar. If a surgical hook is not available, the Sentalloy coil can be engaged to the hook of the canine's bracket. This situation requires the six front teeth to be tied together with either an elastomeric chain or a stainless steel ligature, so they act as a unit.

Minimum Anchorage. On a minimum anchorage situation, molars will be moved mesially to close the remaining extraction spaces. We use a 0.021- × 0.025-inch wire. This wire will express the buccal crown torque of the maxillary incisors and the mesial tip of the canines. In the mandible, this wire will express the mesial tip of the canine. This situation will increase the anchorage in the anterior part of the mouth, because it would be more difficult to retract or even tip back the anterior teeth while moving the molars forward. It also has been recommended to reduce the size of the wire in the posterior part, specifically the edges, in order to decrease the anchorage of the posterior teeth. The activation of the DKH or the Sentalloy coils must be done from the first molars. Then, after the first molar has been moved forward as desired, the second molar can be activated and moved forward, too. Often, though, this is not required because the second molars will travel forward as we move the first molars and then the space remaining between the first and second molars will be very small and easily closed with an elastomeric chain.

Medium Anchorage. This is the most common anchorage situation we will encounter in our cases. Medium anchorage means that the remaining spaces should be closed reciprocally. For this situation, we use a 0.019- × 0.025-inch wire. The activation of the DKH or Sentalloy coils is done, most of the time, from the first molar. However, it can also be done from the second molars depending on how the case is progressing. The bone and attachment apparatus is not the same for every patient, and therefore, the response to the closing mechanic could differ between cases. Then, a clinical examination of the overbite/overjet, canine and molar relationship, and facial aesthetic should be done at each visit to evaluate any changes in activation that may be required. This should not take any extra time, because the activation of a DKH or Sentalloy coil is a rather easy procedure.

Maximum Anchorage. In a maximum anchorage situation, most of the remaining space left after leveling and aligning is closed due to distal movement of the anterior teeth. We use a 0.019- × 0.025-inch wire. The DKH or Sentalloy coil is activated from the second molars. Although not frequently required, auxiliaries to enhance posterior anchorage such as TPB, TADs, or extraoral force (headgear) can be used as needed.

Intermaxillary Elastics. *Discretion* is a good word to describe the use of intermaxillary elastics. We use them and like them, but it is important to understand how they are used to avoid problems. We do not use intermaxillary elastics in the following situations:

- Round wires
- Initial leveling and aligning, low-deflection wires
- To a terminal tooth, last tooth in the arch
- In the anterior part of the mouth to close openbites
- In the posterior part of the mouth to correct crossbites
- For an extended period of time

We use intermaxillary elastics in the following situations:

- At the working and finishing stages
- On square or rectangular stainless steel wires
- On the buccal side of the mouth, short Class II or III and/or triangular verticals

The three types of intermaxillary elastics we commonly use are $\frac{3}{16}$-inch 4 oz, 6 oz, and 8 oz elastics. Short means, in a Class II, for instance, from the maxillary canine to the mandibular second premolar in a nonextraction case and to the first mandibular molar in an extraction case.

The following are the movements we should expect and goals we should accomplish at the working stage before starting stage 3:

- Movement of group of teeth in all planes of the space: sagittal, vertical, and transverse
- Overjet/overbite correction
- Class II and III correction
- Close all remaining extraction spaces aligning maxillary and mandibular midlines
- Finish leveling the occlusal plane
- Arch coordination

The following are the most common wires and sequence used at stage 2 of treatment:

- In nonextraction cases, a 0.019- × 0.025-inch stainless steel wire. Reverse curve of Spee can be manually added to the wire if needed.
- In extraction cases, either a 0.019- × 0.025-inch stainless steel or a 0.021- × 0.025-inch stainless steel wire depending on the anchorage requirement, as previously explained (Tables 16-3 and 16-4).

Stage 3: Finishing Stage. At this stage, to place each tooth on its ideal position and flatten the occlusal plane, full bracket expression is desired and, thus, a larger wire such as a 0.021- × 0.025-inch stainless steel or a 0.022- × 0.028-inch stainless steel may be required. In our experience using the In-Ovation bracket system, which is an active SLB with the clip pushing and sitting the wire onto the slot, often optimal bracket expression is achieved after a 0.019- × 0.025-inch stainless steel has been in place for a few months. This is especially true in nonextraction cases with an average curve of Spee. However, in some cases the size and stiffness of a 0.021- × 0.025-inch stainless steel or 0.022- × 0.028-inch stainless steel are indicated, such as in cases with a deep curve of Spee, extraction cases that have required an important amount of tooth movement, and cases that required significant labial crown torque of maxillary incisors such as Class III camouflage cases and Class II, Division 2 cases. Once the maxillary and mandibular occlusal planes are parallel and all the bracket slots are aligned, bracket position should be carefully checked for minor correction of tooth position and therefore the second time of debond/rebond should be done. It is also suggested, at this point in treatment, to mount the models in an articulator to better visualize the intercuspation of the posterior teeth, which is very difficult to do clinically. The last wire we use is a stainless steel multibraided 0.021- × 0.025-inch archwire. Although this wire is large enough to fill the slot of the bracket and then maintain the tip, torque, and offset of each tooth, its resilience permits both minor bracket repositioning and "end of treatment" optimal intercuspation. It is important to notice that at this point in treatment, all the appliance interferences should be removed using a finishing carbide burr on a high-speed handpiece. With a thin articular paper, all contacts must be checked. Only tooth-tooth contacts should be allowed. All brackets, tubes, or bands contacts must be removed to allow proper settling. Vertical triangular $\frac{3}{16}$-inch elastics, either 6 oz or 8 oz, are used to achieve proper intercuspation. These vertical elastics should not be used with the braided wire for more than 6 weeks to avoid rolling premolars and molars lingually, which can be detected not from the buccal but rather from the lingual, where premolars and/or molars will not be contacting. Finally, before removing the appliance, a complete assessment of the occlusal "end of treatment" goals should be performed. We strive to finish our cases with a static occlusal scheme compatible with the six keys of optimal occlusion described by Andrews[1] and a dynamic mutually protected occlusal scheme in centric relation described by Roth[12] (Table 16-5).

TABLE 16-3 Types of Wires, Size, and Sequence Suggested for Stage 2 of Treatment Mechanics in Nonextraction Cases

STM2 Type	Nonextraction	
	Size (inches)	Sequence (inches)
SW stainless steel	0.019 × 0.025	
Bioforce	0.021 × 0.028	0.019 × 0.025
Reverse curve stainless steel	0.019 × 0.025	

TABLE 16-4 Types of Wires, Size, and Sequence Suggested for Stage 2 of Treatment Mechanics in Extraction Cases

STM2 Type	Extraction	
	Size (inches)	Sequence
SW stainless steel with hooks	0.019 × 0.025 0.021 × 0.025	
or		Depends on anchorage requirement
DKL stainless steel	0.019 × 0.025 0.021 × 0.025	

TABLE 16-5 Types of Wires, Size, and Sequence Suggested for Stage 3 Treatment Mechanics

STM3 Type	Size (inches)	Sequence
SW stainless steel	0.021 × 0.025 0.021 × 0.028	SW stainless steel ↓
Braided stainless steel	0.021 × 0.025	Braided stainless steel

CASE STUDY 16-1

Dr. Antonino G. Secchi

A 20-year-old woman presented with an anterior openbite and a unilateral posterior crossbite (Figure 16-7). The openbite was closed by leveling, aligning, and flattening the maxillary and mandibular occlusal planes. Triangular vertical elastics were used only on the buccal segment at the working and finishing stages. A TPB attached to the maxillary first molars was used to help with arch coordination and correct the unilateral posterior crossbite. An active self-ligating SWA (In-Ovation R and C, GAC International) was used. Active treatment was for 15 months.

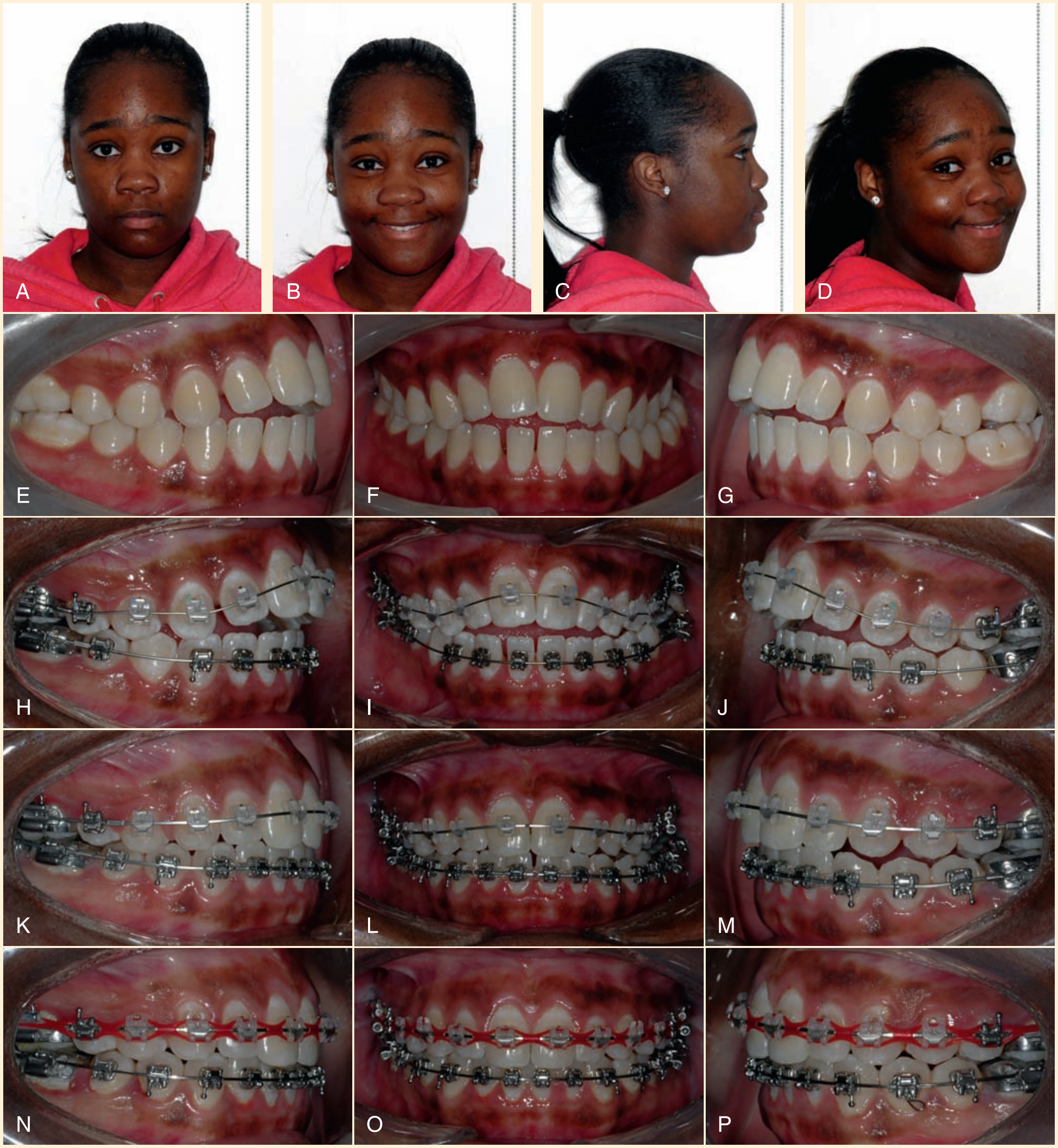

FIGURE 16-7 **A–D,** Facial photographs before treatment. **E–G,** Intraoral photographs before treatment. **H–J,** 0.014-inch Sentalloy initial wires. **K–M,** 0.020- × 0.020-inch Bioforce wires to finish stage 1 of leveling and aligning. **N–P,** 0.019- × 0.025-inch stainless steel working wire to flatten occlusal plane, coordinate arches, and consolidate spaces. Start using triangular vertical elastics.

Continued

CASE STUDY 16-1

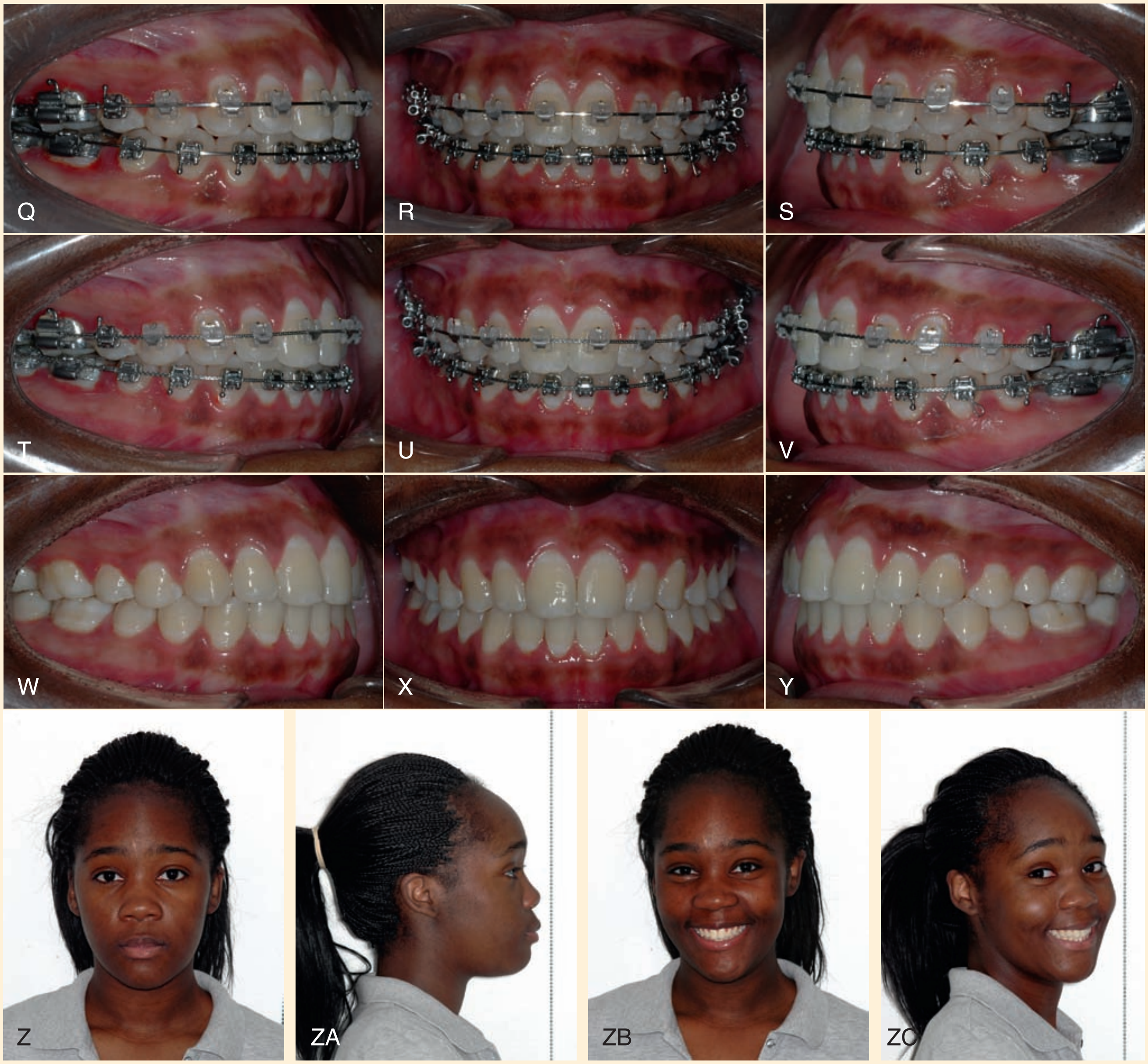

FIGURE 16-7, cont'd **Q–S,** 0.021- × 0.025-inch stainless steel to finalize leveling occlusal plane, continuing with triangular vertical elastics. **T–V,** 0.021- × 0.025-inch stainless steel braided wire, finishing archwire. **W–Y,** Intraoral photographs after treatment. **Z–ZC,** Facial photographs after treatment.

CASE STUDY 16-2

Dr. Antonino G. Secchi

A 14-year-old boy presented with a blocked upper right canine, an end-on molar relationship, and the maxillary midline off to his right (Figure 16-8). Maxillary first premolars and mandibular second premolars were extracted. Medium anchorage was used for the maxillary arch and minimum anchorage for the mandibular arch. An active self-ligating SWA (In-Ovation R) was used. Active treatment was 20 months.

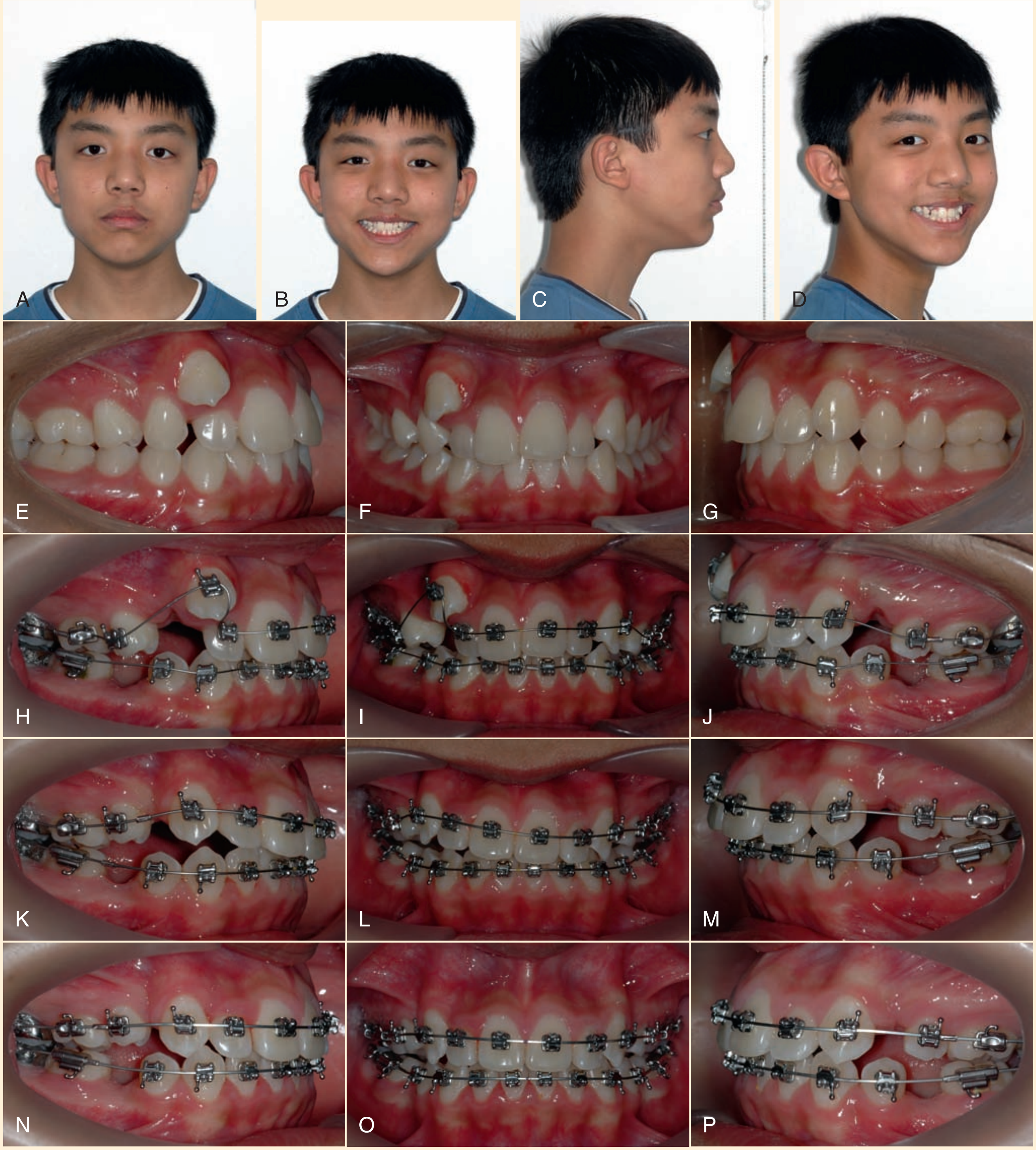

FIGURE 16-8 **A–D,** Facial photographs before treatment**.** **E–G,** Intraoral photographs before treatment. **H–J,** 0.014-inch Sentalloy initial wires. **K–M,** 0.018-inch Sentalloy initial wires to continue with leveling and aligning. **N–P,** 0.020- × 0.020-inch Bioforce wires to correct remaining rotations and start flattening the occlusal plane.

Continued

CASE STUDY 16-2

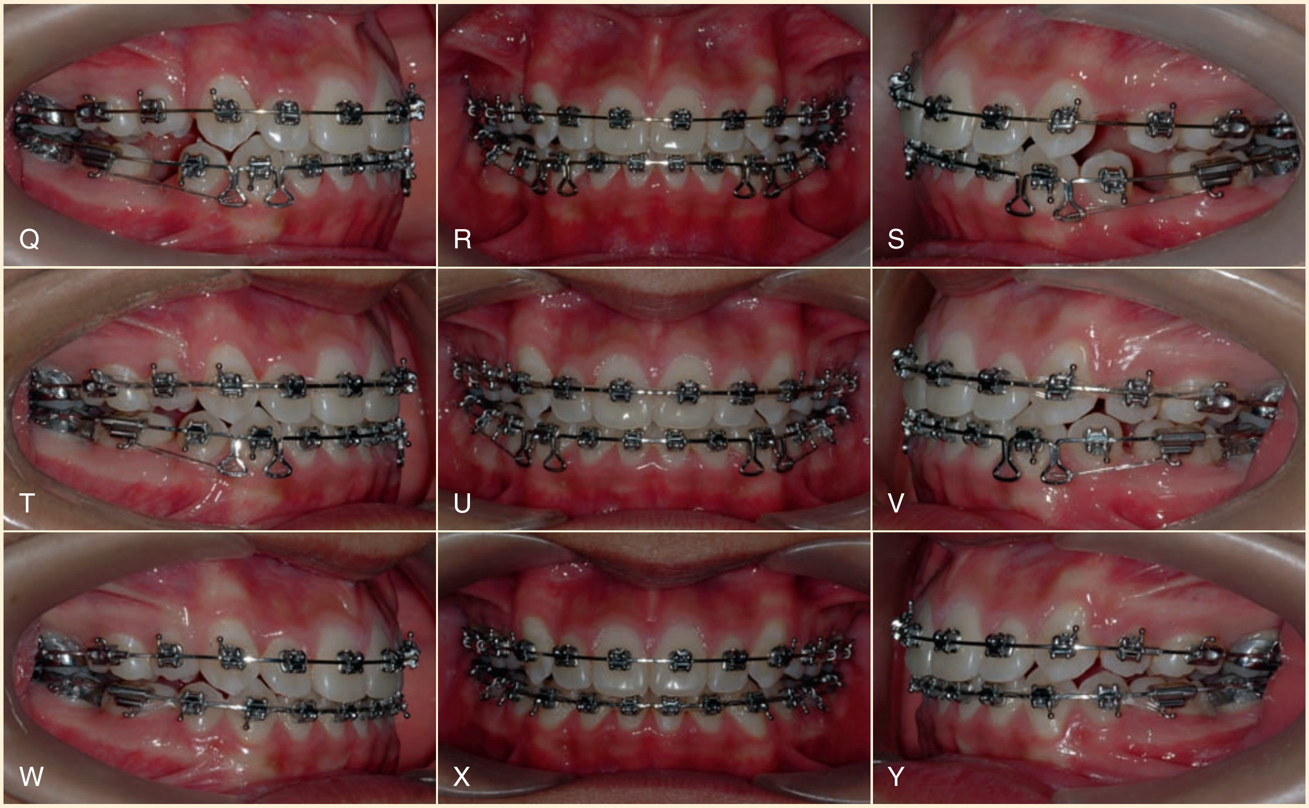

FIGURE 16-8, cont'd **Q–S,** Maxillary 0.019- × 0.025-inch stainless steel wire and mandibular 0.021- × 0.025-inch stainless steel DKL activated with a stainless steel ligature to the first molar for minimum anchorage. At this point patient was asked to wear short Class II $\frac{3}{16}$-inch 4 oz only at night. **T–V,** Extraction spaces closed, Class I molar and canine have been achieved, good overjet/overbite and midlines on. **W–Y,** 0.021- × 0.025-inch stainless steel wires to express torque and level occlusal plane. Triangular vertical elastics $\frac{3}{16}$-inch 6 oz are used.

CASE STUDY 16-2

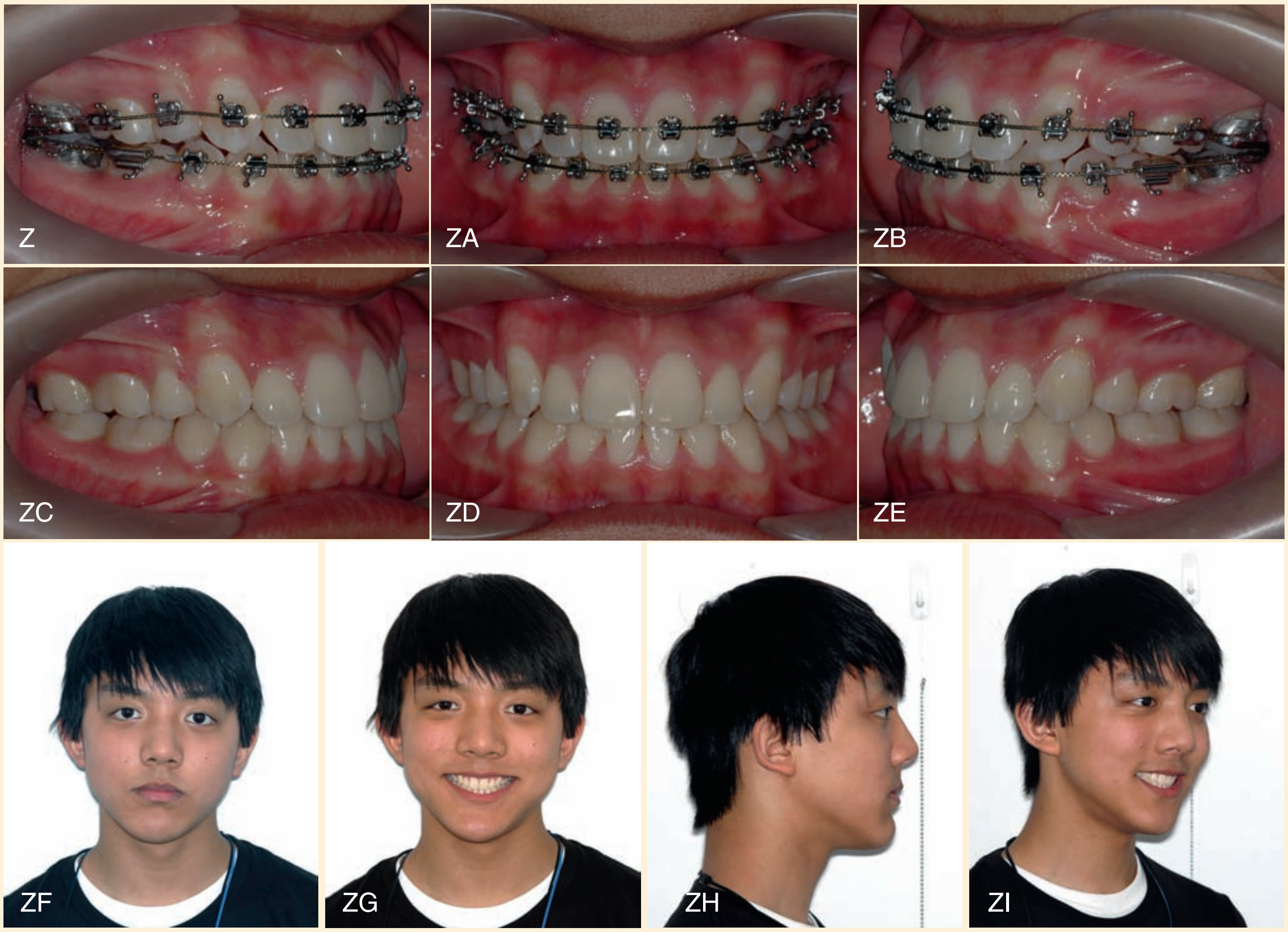

FIGURE 16-8, cont'd **Z–ZB,** 0.021- × 0.025-inch stainless steel braided wire, finishing archwire. Bracket of maxillary right premolar was repositioned to improve final intercuspation. Continue with Triangular vertical elastics $\frac{3}{16}$-inch 6 oz. **ZC–ZE,** Intraoral photographs after treatment. **ZF–ZI,** Facial photographs after treatment.

CASE STUDY 16-3

Dr. Antonino G. Secchi

A 12-year-old girl presented with a deep bite, Class II canines, crowding, and severe retroclination of maxillary incisors (Figure 16-9). After initial leveling and aligning, the mandibular occlusal plane was flattened using a 0.019- × 0.025-inch stainless steel wire with reverse curve of Spee. Short Class II elastics were used at the working stage. Proper buccal crown torque to the maxillary incisors was achieved with a 0.021- × 0.025-inch stainless steel wire. An active self-ligating SWA (In-Ovation R) was used. Active treatment was for 25 months.

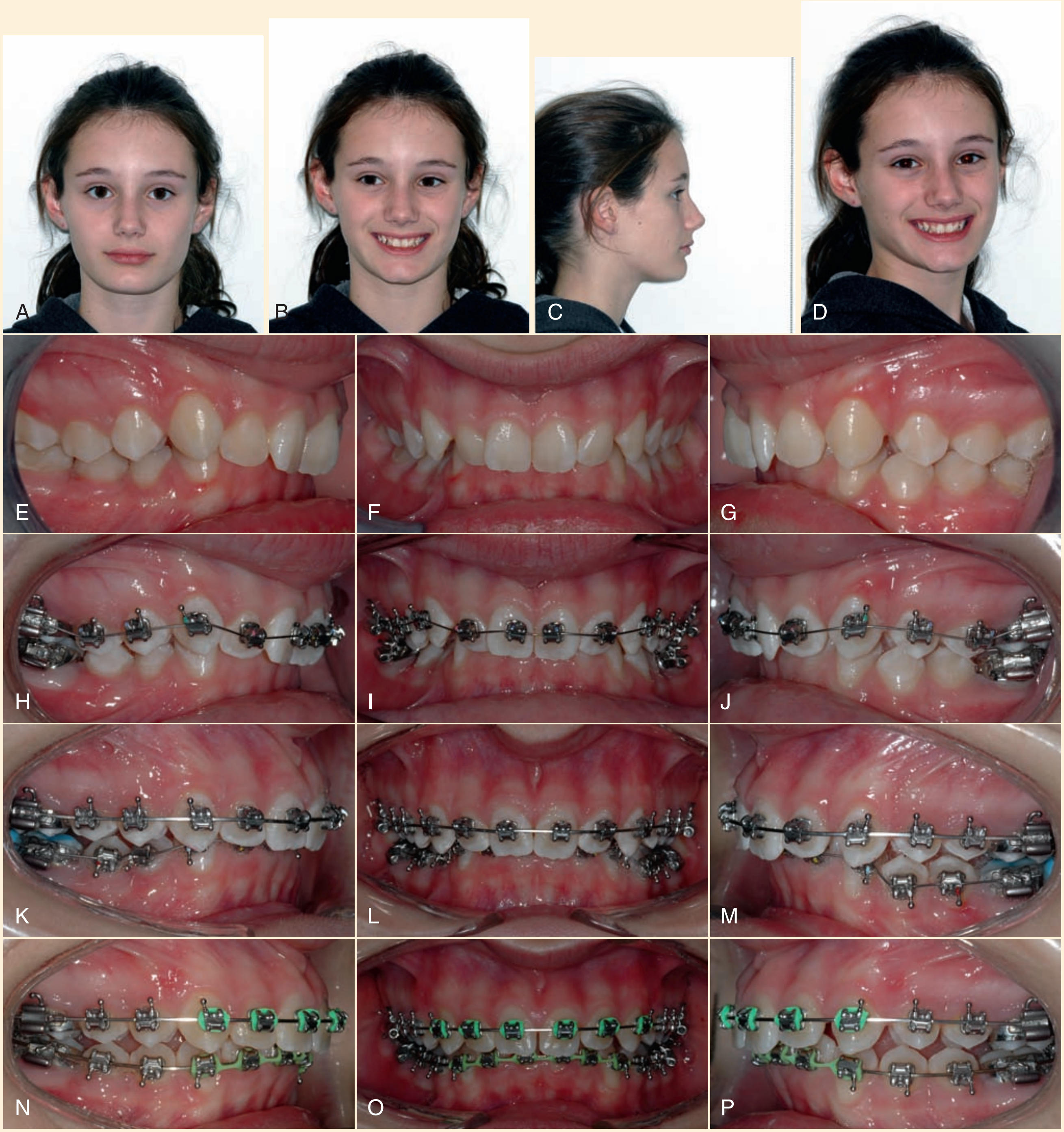

FIGURE 16-9 **A–D,** Facial photographs before treatment. **E–G,** Intraoral photographs before treatment. **H–J,** 0.014-inch Sentalloy initial wires only in the maxillary arch. Mandibular arch was bonded after initial alignment of the maxillary arch was completed. **K–M,** Maxillary 0.019- × 0.025-inch stainless steel wire and mandibular 0.014-inch Sentalloy initial wire. Notice mandibular severe curve of Spee. **N–P,** Mandibular arch with a 0.019- × 0.025-inch stainless steel wire with reverse curve of Spee. At this point patient was asked to use short Class II 6 oz.

CASE STUDY 16-3

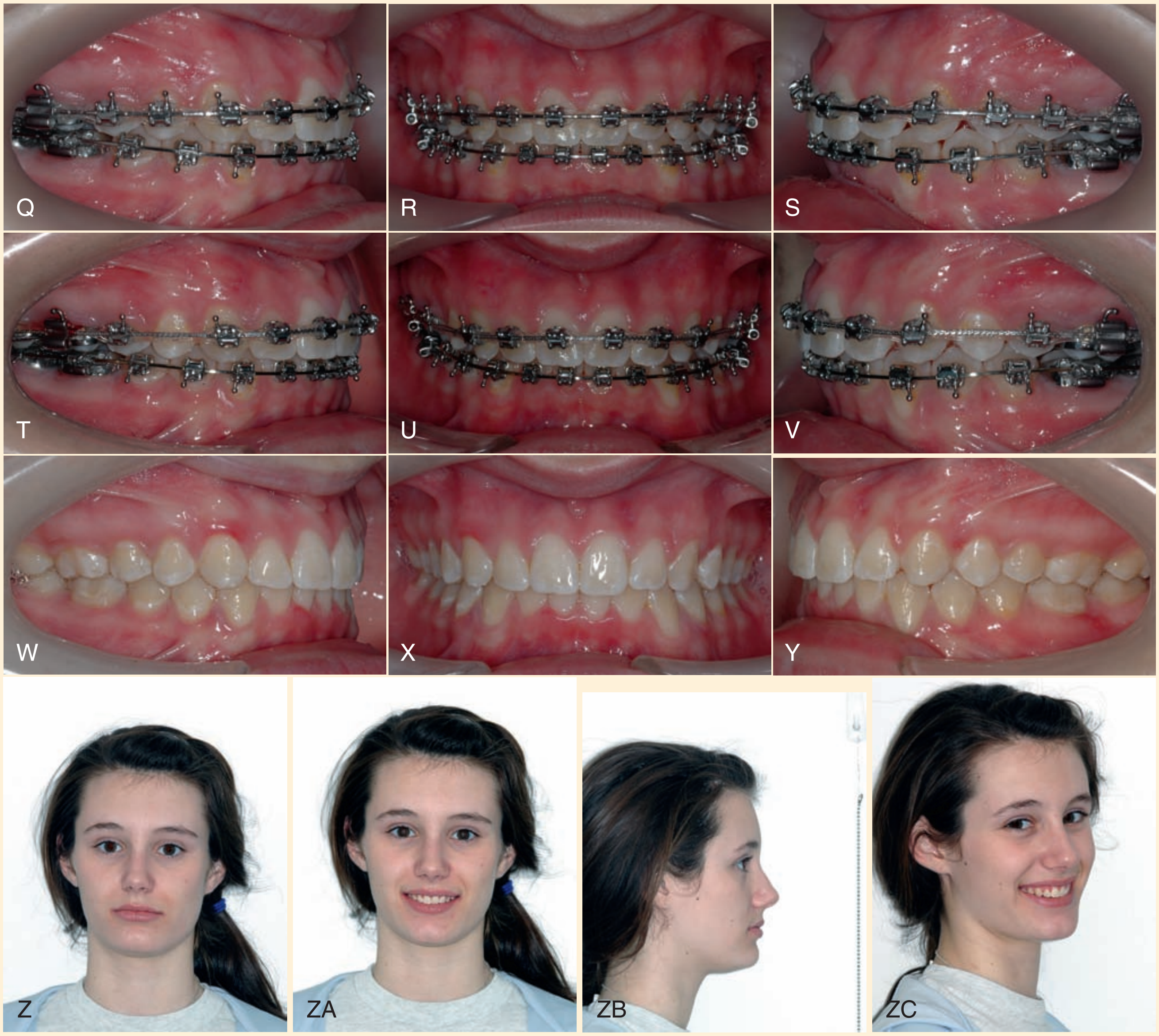

FIGURE 16-9, cont'd **Q–S,** Maxillary 0.021- × 0.025-inch stainless steel wire to express buccal crown torque of incisors. Notice flattening of mandibular occlusal plane due to reverse curve of Spee. **T–V,** 0.021- × 0.025-inch stainless steel braided wire, finishing archwire. **W–Y,** Intraoral photographs after treatment. **Z–ZC,** Facial photographs after treatment.

CASE STUDY 16-4

Dr. Antonino G. Secchi

A 16.5-year-old boy presented with a deep bite, dental Class II molar and canine on the right side, and midlines off (Figure 16-10). After stage 1, leveling and aligning, was completed and the working wires of 0.019- × 0.025-inch stainless steel were in place, an open coil was packed between the maxillary right second premolar and first molar to move the first and second molars distally to a Class I. The patient was asked to use a short Class II 4 oz elastic as anchorage. After the molars were moved as desired, the coil was placed between the premolar and then between the canine and the first premolar to move them back. It is very important to have the maxillary occlusal plane flat before starting to move the molars. This type of mechanics is contraindicated in skeletal Class II cases and/or cases with a vertical pattern. An active self-ligating SWA (In-Ovation R) was used. Active treatment was for 26 months.

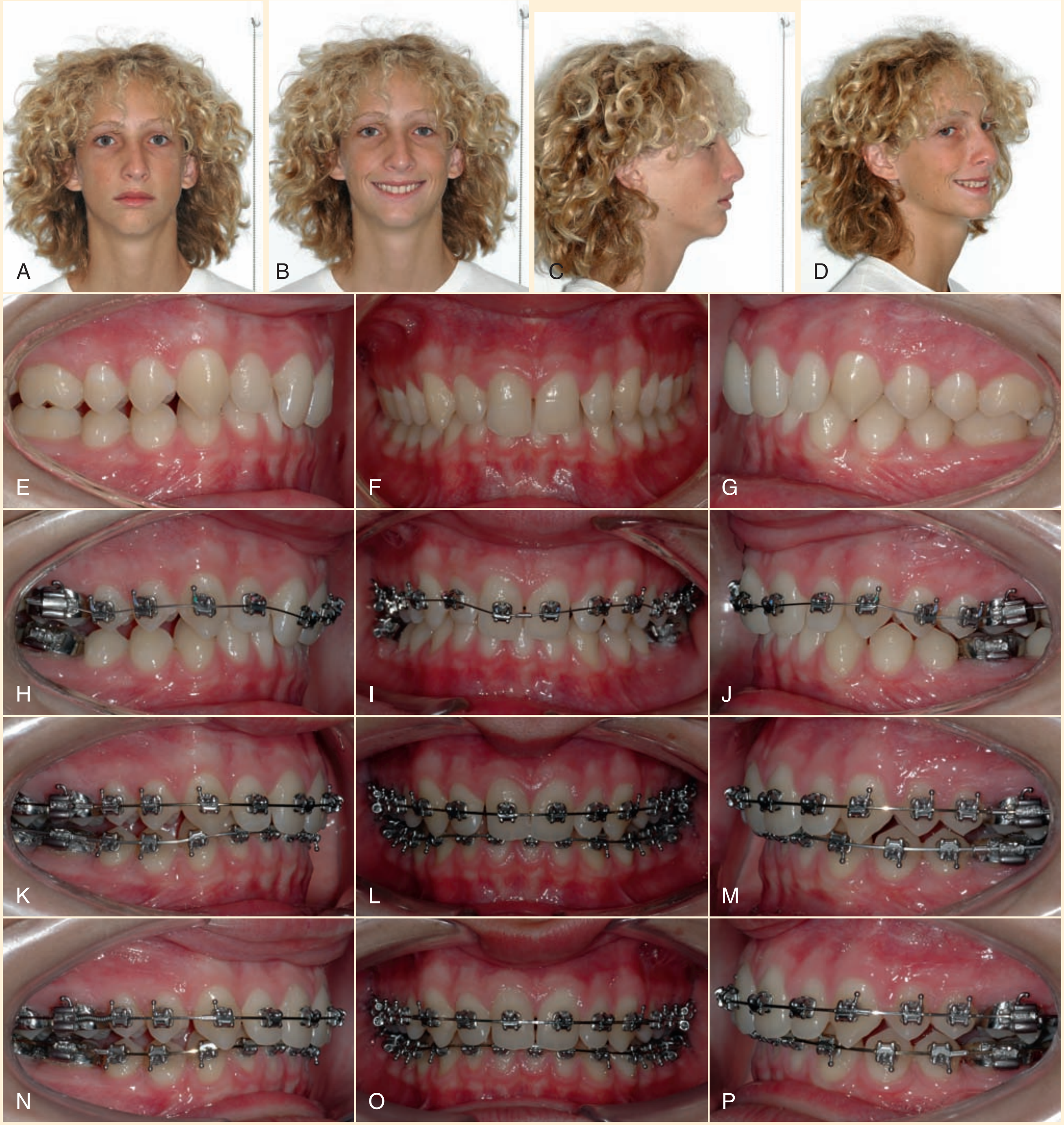

FIGURE 16-10 **A–D,** Facial photographs before treatment. **E–G,** Intraoral photographs before treatment. **H–J,** 0.014-inch Sentalloy initial wires only in the maxillary arch. Mandibular arch was bonded after initial alignment of the maxillary arch was completed. **K–M,** Maxillary 0.019- × 0.025-inch stainless steel wire and mandibular 0.020- × 0.20-inch Bioforce wire. **N–P,** Maxillary and mandibular 0.019- × 0.025-inch stainless steel wire. An open coil is packed between the right second premolar and first molar. Patient was asked to use a short Class II 6 oz elastic as anchorage.

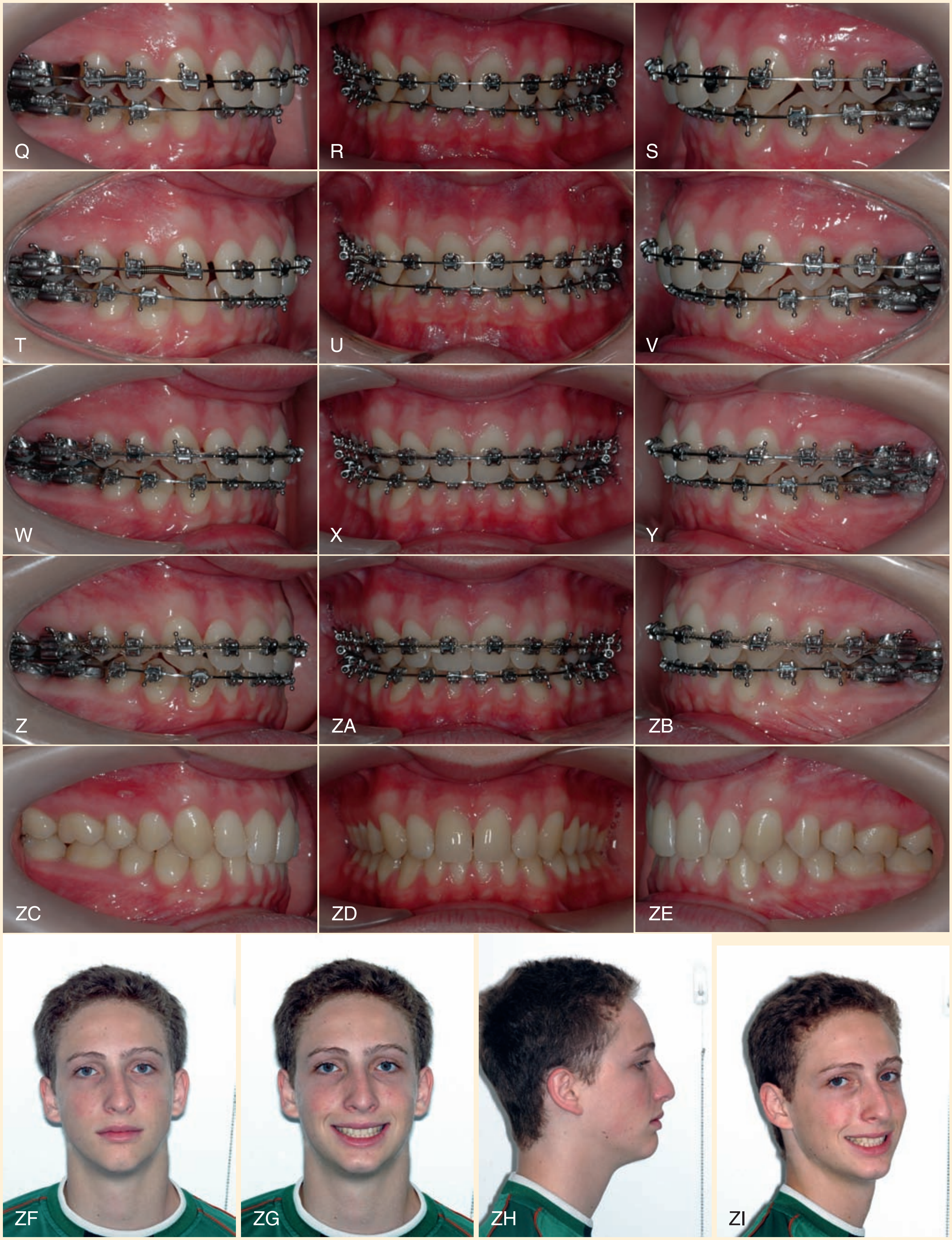

FIGURE 16-10, cont'd **Q–S,** Notice distal movement of maxillary right molars to a Class I. Open coils was moved and placed between first and second premolars. **T–V,** Notice distal movement of premolars. **W–Y,** Maxillary and mandibular 0.021- × 0.025-inch stainless steel wire to express torque, flatten the occlusal plane. Elastomeric chain to consolidate spaces and use of triangular vertical elastics. **Z–ZB,** Final 0.021- × 0.025-inch stainless steel braided wire for the maxilla and 0.021- × 0.025-inch stainless steel wire for the mandible. Continue with triangular vertical elastics. **ZC–ZE,** Intraoral photographs after treatment. **ZF–ZI,** Facial photographs after treatment.

SUMMARY

The advantages of the SWA are unquestionable. At 40 years after its introduction to our specialty, it remains the most popular orthodontic appliance used in the world. But today, at the beginning of this twenty-first century, the challenge is to integrate the SWA with recent changes in bracket design such as self-ligation and technologically advanced low-deflection thermal-activated archwires to provide orthodontists with a state-of-the-art appliance system that can deliver, through a practical, efficient, and reliable biomechanical system, excellent results for a wide range of dentofacial problems. Our objective was to delineate some of the basic principles of the SWA, emphasize the importance of optimal bracket placement, and, finally, provide the reader with the framework of a simple, but complete, biomechanics tailored for active SLBs.

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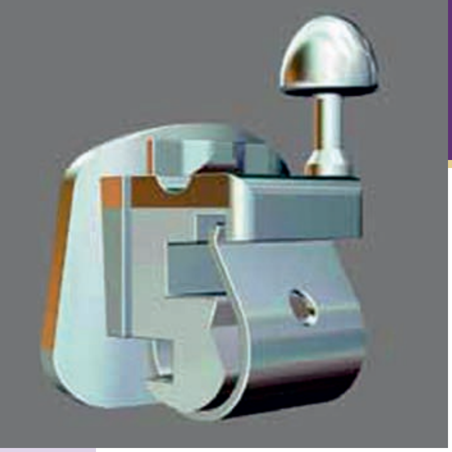

CHAPTER 17

Self-Ligating Brackets: Theory, Practice, and Evidence

Nigel Harradine

OUTLINE

- **The Historical Context of Self-Ligation**
  - Stainless Steel Ligatures
  - Elastomeric Ligatures
  - Begg Pins
  - Self-Ligation
- **Factors that Have Hindered the Adoption of Self-Ligation**
  - Psychological Factors and Adoption of Self-Ligation
- **Aesthetic Self-Ligating Brackets**
- **Proposed Core Advantages of Self-Ligating Brackets**
  - The Speed of Archwire Insertion and Removal
  - Secure Archwire Engagement
  - Friction and Self-Ligation
    - *Friction with Active Wires*
    - *Friction In Vivo—Occlusal and Masticatory Forces*
  - Secure Ligation and Low Friction as a Combination of Properties
  - The Clinical Significance of Low Friction
- **Self-Ligation and Treatment Efficiency**
  - The “Nickel-Titanium” Dilemma
- **Active Clips and Passive Slides**
  - Thin Aligning Wires Smaller Than 0.018-Inch Diameter
  - Wires Larger Than 0.018-Inch Diameter
  - Thick Rectangular Wires
  - Aging of Spring Clips
  - Active or Passive—Conclusion
    - *Alignment*
    - *Friction*
    - *Robustness and Ease of Use*
- **Self-Ligation and Patient Comfort**
- **Self-Ligation and Effectiveness of Torque Control**
- **Further Current Hypotheses about Self-Ligation**
- **Force Levels with Self-Ligation and Conventional Ligation**
- **Does Self-Ligation Reduce the Need for Extractions?**
  - Crowding
- **Practical Consequences for Clinical Technique**
  - Choice of Self-Ligating Bracket
  - Practical Tips in Light of the Evidence
- **Summary**

THE HISTORICAL CONTEXT OF SELF-LIGATION

In the context of the current popularity of self-ligation and the plethora of types of self-ligating bracket, it is helpful to review the origins and motivations for development of this form of ligation. The vast majority of fixed orthodontic appliances have stored tooth-moving forces in archwires, which are deformed within their elastic limit. For this force to be transmitted to a tooth, wires need a form of connection to the bracket. This connection has for many years been referred to as “ligation” because the early forms of connection were most frequently a type of ligature—for example, silk ligatures. The more recent forms of connection between bracket and archwire have all retained this title of ligation. “Elastomeric ligatures” and “self-ligating brackets” are firmly established orthodontic terms.

Stainless Steel Ligatures

When stainless steel became available, this was universally adopted as the method of ligation. Stainless steel ligatures have several beneficial inherent qualities. They are cheap, robust, and essentially free from deformation and degradation, and to an extent they can be applied tightly or loosely to the archwire. They also permit ligation of the archwire at a distance from the bracket. This distant ligation is particularly useful if the appliance tends to employ high forces from the archwires, because this high force prevents sensible full archwire engagement with significantly irregular teeth. Despite these

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good qualities and their widespread use over many decades, wire ligatures have substantial drawbacks, and the most immediately apparent of these are the length of time required to place and remove the ligatures. One typical study[1] found that an additional 11 minutes was required to remove and replace two archwires if wire ligatures were used rather than elastomeric ligatures. Additional potential hazards include those arising from puncture wounds from the ligature ends and trauma to the patients' mucosa if the ligature end becomes displaced.

Elastomeric Ligatures

Elastomeric ligatures became available in the late 1960s and rapidly became the most common means of ligation, almost entirely because of the greatly reduced time required to place and remove them when compared with steel wire ligatures. It was also easier to learn the skills required to place these ligatures, so new clinicians and staff greatly preferred elastomerics. Intermaxillary elastics had been employed since the late nineteenth century, pioneered by well-known orthodontists such as Calvin S. Case and H. A. Baker. Initially these elastic bands were made from natural rubber, but production of elastomeric chains and ligatures followed the ability to produce synthetic elastics from polyester or polyether urethanes. The ease of use and speed of placement of elastomerics ligatures did, however, lead to other definite disadvantages being generally overlooked, although readily apparent. Elastomerics frequently fail to fully engage an archwire when full engagement is intended. Twin brackets with the ability to "figure-of-eight" the elastomerics are a significant help in this respect but at the cost of greatly increased friction, which will be discussed later in this chapter. Khambay et al.[2] quantified the potential seating forces with wire and elastic ligatures and clearly showed the much higher archwire seating forces available with tight wire ligatures. A second and well-documented drawback with elastomerics is the substantial degradation of their mechanical properties in the oral environment. A comprehensive literature review of elastomeric chains[3] gave a good account of the relevant data, and a more recent article[4] discusses the underlying reasons and clinical significance of this loss of mechanical properties. Typically elastomeric chains and ligatures undergo greater than 50% degradation in force in the first 24 hours[5] when tested under in vitro experimental environments. The higher temperature in the mouth, enzymatic activity, and lipid absorption by polyurethanes are all cited as in vivo sources of force relaxation. This leads to the well-known potential for elastomeric ligatures to fail to achieve or to maintain full archwire engagement in the bracket slot.

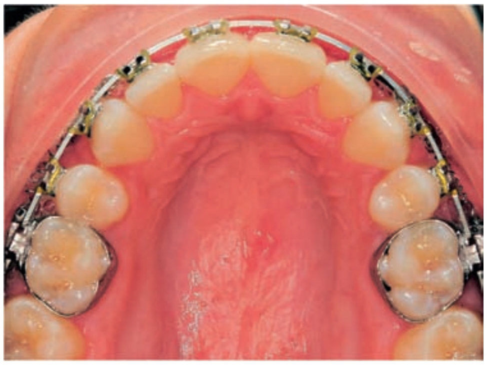

FIGURE 17-1 Loss of archwire control with elastomeric ligation.

Figure 17-1 shows the familiar loss of rotational control of canines during space closure. Twin brackets with the ability to "figure-of-eight" the elastomerics are a significant help in this respect but certainly not a complete answer. A further factor of potential clinical importance is the variability in mechanical properties of elastomerics. This is well described by Lam et al.,[6] who reported substantial variation in the range and tensile strength of elastomerics from different manufacturers and for different colors of elastomeric from the same manufacturer. Last, there is a large body of literature to demonstrate the much higher friction between bracket and archwire with elastomeric ligation compared with wire ligatures. Interestingly, this had been proposed as a factor of clinical significance more than 30 years ago[7] but was largely disregarded until more recently. The potential importance of friction and its relation to forms of ligation will be discussed in more detail later in this chapter. The great popularity of elastomeric ligation in the last 40 years was achieved despite these substantial deficiencies in relation to wire ligatures. Speed and ease of use were the overriding assets of elastomerics, and it is no surprise that the strongest motivation behind the early efforts to produce a satisfactory self-ligating bracket was a desire to have all the benefits of wire ligation but in addition to have a system that was quick and easy to use.

Begg Pins

In the 1950s, Raymond Begg, a former pupil of Edward Angle, developed his light wire technique using Angle's ribbon arch brackets with round wire archwires.[8] A key feature of the technique was the use of brass pins as the method of ligation. These pins constituted the fourth (gingival) wall of the bracket slot and formed a rigid metal wall analogous in some ways to that of a molar tube or a self-ligating bracket. The pins were designed with shoulders to keep from binding the archwire in the early alignment stages and without shoulders as "hook-pins" to hold the archwire in a more precise vertical position when thicker wires and auxiliaries were added later in the treatment. This author used many such pins, being trained simultaneously in Begg and Edgewise mechanics during his initial specialist training. Begg pins had none of the disadvantages of elastomeric rings and were probably more rapid to place and remove than wire ligatures. These pins cannot be assessed in complete isolation from the rest of the Begg technique but in relation to self-ligation, it is well worth noting the reputation that the Begg technique acquired for rapid early alignment and the effectiveness of lighter forces when there was no friction to be overcome from tight engagement with elastomerics. As a footnote in orthodontic history, it should be recalled that self-ligating Begg brackets were produced in the 1970s and were used by this author on a number of cases. They had an inbuilt pin that was rotated into position over the archwire with the intention being to further simplify and speed the process of ligation. Interestingly, when the Tip-Edge appliance was developed to be a successor to the Begg technique, it abandoned the metal, low-friction form of ligation that Begg pins represented and reverted to elastomerics.

Self-Ligation

Self-ligating brackets by definition do not require an elastic or wire ligature but have an inbuilt mechanism that can be opened and closed to secure the archwire. In the overwhelming majority of designs, this mechanism is some form of metal labial face to the bracket slot that is opened and closed with an instrument or finger tip. Brackets of this type have existed for a surprisingly long time in orthodontics—the Russell Lock edgewise attachment being described by Stolzenberg[9] in 1935. This was by modern standards a very primitive mechanism consisting of a labial grub-screw to retain the archwire. Since that time, many designs have been patented, although only a minority of those became commercially available. Self-ligating orthodontic brackets have a relatively long history, but their development should be viewed against the background of an almost universal use of elastomeric ligatures despite the known advantages of wire ligatures and—in a different context—of brass Begg pins. Elastomeric ligation gives unreliable archwire control, high friction, and perhaps an added oral hygiene challenge. Wire ligation is better in every respect, but is very slow, highly inconsistent in its force application[10] and the wire ends can cause trauma to patient and operator. Orthodontists accommodated these shortcomings for several decades. Self-ligation has always offered the potential for very substantial improvements in relation to all of these drawbacks, but for many years remained the choice of a small minority of clinicians.

Table 17-1 is not exhaustive but includes a majority of the brackets produced commercially. It can be seen that there has been a dramatic acceleration of bracket development with at least 23 new bracket types becoming available between 2000 and 2009. An overview of the status of self-ligation earlier in the current century[11] summarizes the situation at that time. Recent years have also seen an expansion of the advocated advantages of self-ligation and, more recently, a much greater research effort to gather the necessary related evidence. Before examining these claims and the associated evidence, it is helpful to look at the reasons why it has taken so long for self-ligation to attract this degree of attention.

TABLE 17-1 **Self-Ligating Brackets by Year of Manufacture**

Bracket	Year
Russell Lock	1935
Ormco Edgelok	1972
Forestadent Mobil-Lock	1980
Orec Speed	1980
"A" Company Activa	1986
Adenta Time	1994
"A" Company Damon SL	1996
Ormco TwinLock	1998
Ormco/"A" Co. Damon 2	2000
Gestenco Oyster	2001
GAC In-Ovation	2002
GAC In-Ovation R	2002
Adenta Evolution LT	2002
Ultradent Opal	2004
Ormco Damon 3	2004
3M Unitek SmartClip	2004
Ormco Damon MX	2005
Class One/Ortho Organisers Carrière LX	2005
Forestadent Quick	2006
Lancer Praxis Glide	2006
GAC In-Ovation L	2006
Ultradent OPAL metal	2006
Forestadent Quick	2006
Lancer Praxis Glide	2006
GAC In-Ovation C	2006
3M Unitek Clarity SL	2007
American Orthodontics Vision LP	2007
Dentaurum Discovery SLB	2007
Ortho Technology Lotus	2008
OrthoClassic Axis	2009
Damon Q	2009
Damon Clear	2010

FACTORS THAT HAVE HINDERED THE ADOPTION OF SELF-LIGATION

In part this has been the result of significant imperfections in bracket performance. These imperfections have varied with different bracket designs and can be illustrated by examples from Table 17-1. The author of this chapter has used 15 of the types in that box and is therefore in a position to speak from some experience as well as from first principles. An ideal self-ligating bracket should deliver ligation that is rapid and secure and provides low resistance to tooth movement relative to the archwire, but in addition such a bracket should:

- Be very easy to open and close with low forces applied to the teeth during these procedures and with all archwire sizes and materials
- Never open inadvertently, allowing loss of tooth control
- Have a ligating mechanism that never jams or breaks or distorts or changes in its performance through the treatment period
- Have a positively held open clip/slide position so that the clip or slide does not obstruct the view of the bracket slot or the actual placement of the archwire
- Be tolerant of a reasonable excess of composite material without obstructing the clip/slide mechanism
- Permit easy attachment and removal of all the usual auxiliary components of an appliance such as elastomeric chain, undertie ligatures, and laceback ligatures without interfering with the self-ligating clip/slide
- Permit easy placement and removal of hooks/posts and possibly other auxiliaries on the brackets. With the security of self-ligation, the use of elastics or other traction directly to a bracket is much more frequently appropriate than with conventional ligation
- Have a suitably narrow mesiodistal dimension to take advantage of the secure archwire engagement and permit large interbracket spans and hence lower force levels and a longer range of action
- Have the performance expected of all orthodontic brackets in terms of bond strength and smoothness of contour

Many brackets have been less than satisfactory in several of these requirements, and a representative selection can be used to illustrate the difficulties experienced over the years in producing the ideal bracket or at least a bracket with acceptable fulfillment of these criteria.

- Edgelok brackets[12] (Ormco Corporation, 1717 W. Collins Avenue, Orange, CA 92867) (Figure 17-2) were the first self-ligating bracket to be produced in significant quantities. Disadvantages included inadequate rotational control, bulkiness, and some inconvenience with opening and closing the slide, and they were never widely adopted.
- The well-known Speed brackets[13] (Figure 17-3) have remained in successful production since 1980. This testifies to the inherent soundness of many of the original design features. However, early brackets (Figure 17-4) were handicapped by clips that could too easily be displaced or distorted. These drawbacks have since been successfully addressed by improvements in the bracket body and in the clip itself, but combined with the inherent unfamiliarity for clinicians of a bracket with no tie-wings, these aspects probably hindered the wider popularity of Speed in previous years.

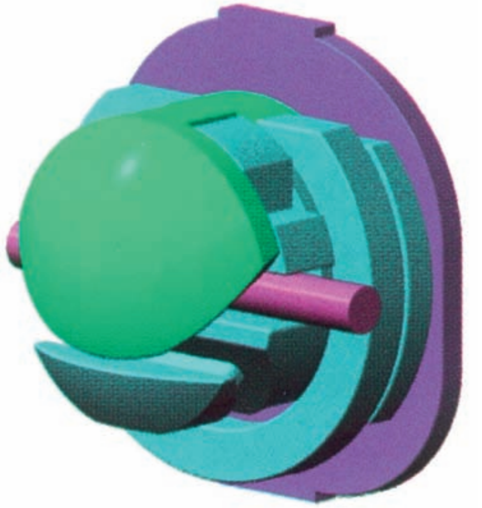

FIGURE 17-2 Edgelok bracket. An early passive self-ligating bracket.

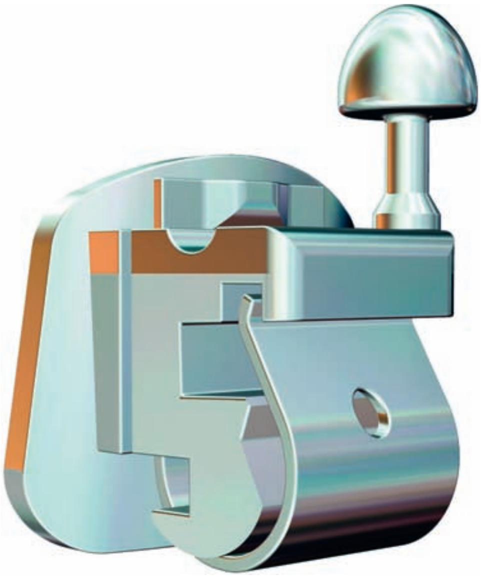

FIGURE 17-3 Speed bracket with clip-restraining slot, labial clip-opening aperture, and slot preadjustment.

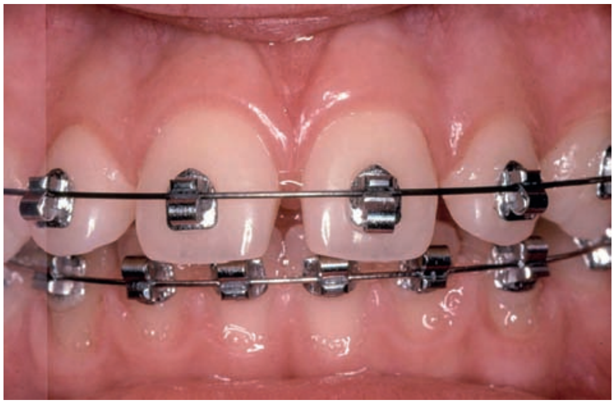

FIGURE 17-4 A case treated with early Speed brackets in 1982. There is no restraining slot preventing clip displacement and no straight-wire preadjustment in the bracket.

- Mobil-Lock brackets (Forestadent Bernhard Foerster GmbH, Westliche 151 75173 Pforzheim, Germany) (Figure 17-5) had a rotating cam that was turned with a "screwdriver," thus covering part of the labial surface of the slot. The wire could be tightly or loosely engaged by the degree of rotation of the cam. This ability to selectively lock a tooth to the archwire to prevent its movement is certainly theoretically desirable, but no other bracket has incorporated this feature. These brackets were well engineered by the standards of the day, but a major limitation was the narrowness of the resulting labial face of the slot. This gave very poor rotational control to the extent that upper incisor brackets were given twin cams to increase the effective bracket width. Another problem was the difficulty of access to open and close premolar brackets with the straight "screwdriver."
- Activa brackets[14] ("A" Company) (Figure 17-6) had a rotating slide that therefore gave a concave inner radius to the labial surface of the slot. This curvature increased the effective slot depth with small-diameter wires, diminishing labiolingual alignment with such wires. The slide was retained on the mesial and distal ends of the slot, and this made for a wider-than-average bracket, which reduced the interbracket span with the consequent disadvantages and the slide was not robust. The absence of tie-wings was an additional nuisance when placing elastomeric chain, and the unfamiliar shape of the early bonding base made bracket positioning more difficult. Finally, a combination of the design features substantially reduced bond strength. Despite these substantial drawbacks, cases could be successfully treated that demonstrated the now-familiar potential advantages of self-ligation, but the deficiencies of the design ensured that they were adopted by only a minority of enthusiasts.
- Damon SL brackets[15,16] ("A" Company) (Figure 17-7) became available in the mid 1990s and had a slide that wrapped round the labial face of the bracket.

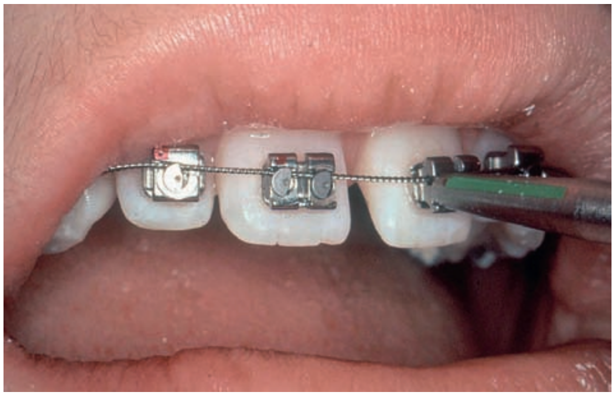

FIGURE 17-5 Mobil-lock brackets. The lack of rotational control is evident on the lateral incisor and from the need to have two ligating mechanisms on the central incisor.

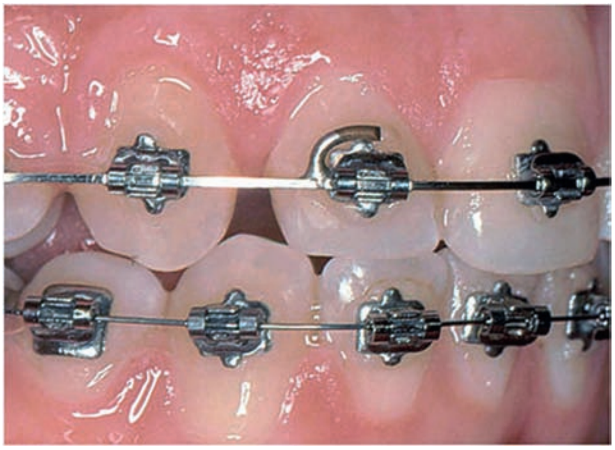

FIGURE 17-6 Activa brackets in 1990, illustrating the undesirable bracket width that reduces interbracket span, the concavity of the rotating clip, the lack of tie-wings, and the unorthodox bonding base.

These brackets were a definite step forward but had two significant problems—the slides sometimes opened inadvertently due to the play of the slide round the exterior of the bracket, and they were prone to breakage due to work-hardening on the angles of the slide during manufacture. One study[17] quantified these problems. In 25 consecutive cases in treatment for more than one year, 31 slides broke and 11 inadvertently opened between visits. This compared with 15 broken and lost elastomeric ligatures in 25 consecutively treated cases with conventional brackets, so the difference in ligation fragility was not enormous, but when a clinician has paid extra for a novel bracket design and the main design feature is not highly robust and is susceptible to inexpert handling from inexperienced operators, it has a significant negative effect on widespread adoption of that bracket. Nevertheless, these brackets generated a

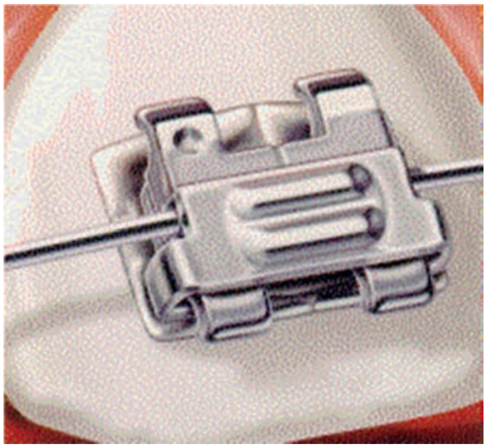

FIGURE 17-7 Damon SL bracket 1996, showing the wraparound slide, which was prone to fracture and loss.

substantial increase in the appreciation of the potential of self-ligation.

- Damon 2 brackets (Ormco Corporation) (Figure 17-8) were introduced to address the imperfections of Damon SL.

They retained the same vertical slide action and U-shaped spring to control opening and closing, but placed the slide within the shelter of the tie-wings. Combined with the introduction of metal injection molding manufacture, which permits closer tolerances, these developments almost completely eliminated inadvertent slide opening or slide breakage and led to a further acceleration in the use of self-ligation. However, the brackets were not immediately and consistently easy to open and this aspect of functionality is very important to the new user. Also, it was possible for the slide to be in a half-open position, hindering archwire removal or placement.

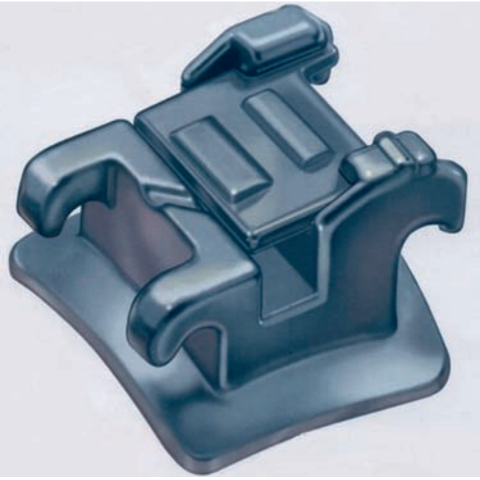

FIGURE 17-8 Damon 2 bracket released in 2000, showing the more protected and more rigid slide, which was produced by metal injection molding (MIM), as was the bracket body.

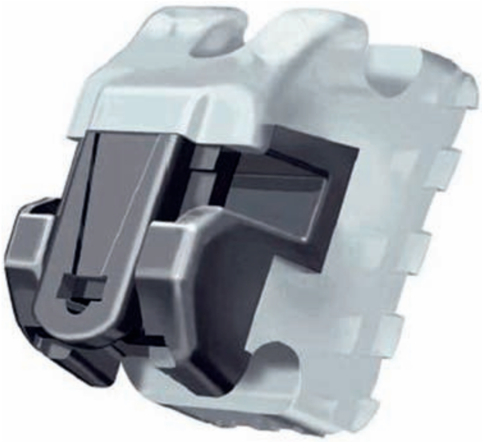

FIGURE 17-9 Damon 3 semiaesthetic bracket showing the improved slide mechanism and the junction of metal and resin components, which was initially prone to separation.

- Damon 3 brackets (Ormco Corporation) (Figure 17-9) had a different location and action of the retaining spring, and this produced a very easy and secure mechanism for opening and closing.

In addition, Damon 3 brackets are semiaesthetic. However, early Damon 3 production brackets had three very significant problems: a high rate of bond failure, separation of the metal from the reinforced resin components, and fractured resin tie-wings. These three problems all received fairly rapid investigation and improvement but illustrate that it continues to be a significant challenge for manufacturers to extrapolate from the experience with prototype brackets in the hands of skilled enthusiasts to subsequent full-scale production and the use by relative novices. The more recently launched all-metal Damon D3 MX bracket (Figure 17-10) and subsequent Damon Q bracket (Figure 17-11) have clearly benefited from previous manufacturing difficulties and from further clinical experience and expertise. As with other brackets such as Speed and In-Ovation (GAC International Inc., 355 Knickerbocker Avenue, Bohemia, NY 11716), these later Damon brackets also

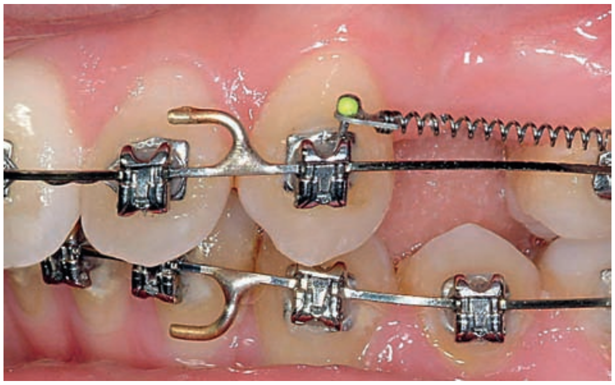

FIGURE 17-10 Damon MX brackets showing the vertical slot, which permits placement and removal of drop-in hooks in this bracket and in the Damon Q.

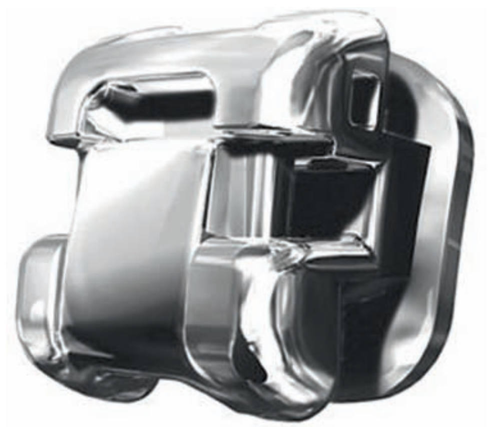

FIGURE 17-11 Damon Q bracket showing the additional horizontal slot for auxiliary archwires—a feature of several self-ligating brackets including In-Ovation, Quick, and Speed.

feature a slot for drop-in hooks, which was mentioned earlier in the list of ideal requirements.

In-Ovation brackets (see Figure 17-12) became available in 2002 and have more recently been called In-Ovation R brackets. They are very similar to the Speed bracket in conception and design but of a twin configuration with tie-wings. Both of these additional features probably contributed to a greater acceptability of these brackets to the new user. In 2002, smaller brackets for the anterior teeth became technically possible and available as In-Ovation R (Reduced—referring to the reduced bracket width), and this narrower width was certainly desirable in terms of greater interbracket span. Several self-ligating brackets have become smaller with development. This has been enabled by advances in manufacturing technology but is also driven by an appreciation that a self-ligating bracket requires less bracket width to give good rotational control. In-Ovation is certainly a successful design, but some relatively minor disadvantages in relation to the list of ideal requirements can be experienced with the several types of bracket that use a spring clip that moves vertically behind the archwire slot. Some brackets with this type of clip are a bit difficult to open, and this is more common in the lower arch where the gingival end of the spring clip is difficult to visualize. Excess composite at the gingival aspect of brackets in the lower arch can be difficult to see and may also hinder opening. Similarly, lacebacks, underties, and elastomerics placed behind the archwire are competing for space with the bracket clip. Interestingly, both Speed and In-Ovation R and the similar and more recent Quick brackets (Figure 17-13; Forestadent Bernhard Foerster GmbH) have aimed to address some aspects of this potential difficulty by providing a labial hole or notch in the clip in which a probe or similar instrument can be inserted to open the clip.

The need to acquire the expertise of opening an unfamiliar bracket can dishearten the new user of self-ligating brackets, and these more recent refinements of the method of opening are a definite advance in this respect. These refinements are also typical of the incremental improvement of self-ligating brackets, which can take place without being appreciated by clinicians who have experienced difficulties with earlier production examples and consequently discontinued their use.

- SmartClip (3M Unitek, 3M Center, St. Paul, MN 55144-1000). This bracket (Figure 17-14) is distinctive in retaining the wire through two C-shaped spring clips on either side of the bracket slot. The pressure required to insert or remove an archwire is therefore not applied directly to a clip or slide but to the archwire, which in turn applies the force to deflect the clips and thus permit archwire insertion or removal. This mechanism therefore has to cope with providing easy insertion and removal through the jaws of the clips but must also prevent inadvertent loss of ligation for both small, flexible archwires and large, stiff archwires. This is an inherent conflict in requirements and one that is difficult to balance satisfactorily. Other spring clips, such as on Speed and

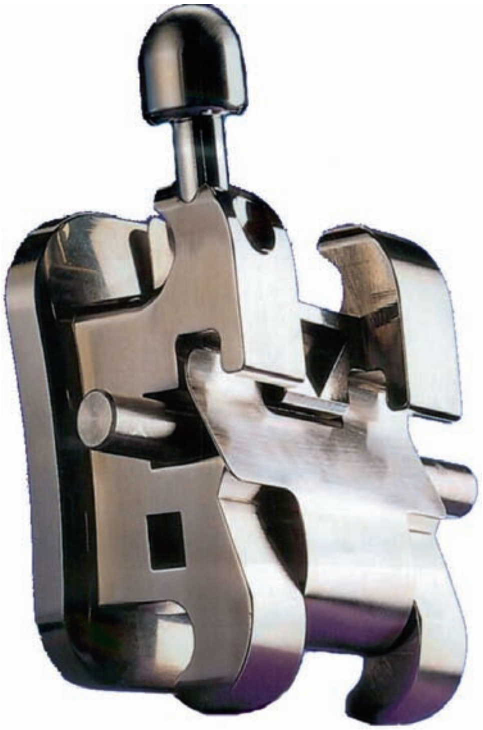

FIGURE 17-12 An early In-Ovation bracket showing the tie-wings, which distinguished this bracket from Speed brackets.

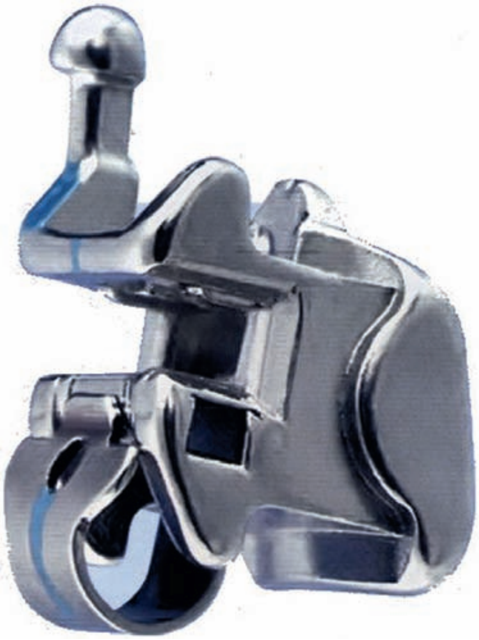

FIGURE 17-13 Forestadent Quick bracket showing the design features shared by many active self-ligating brackets.

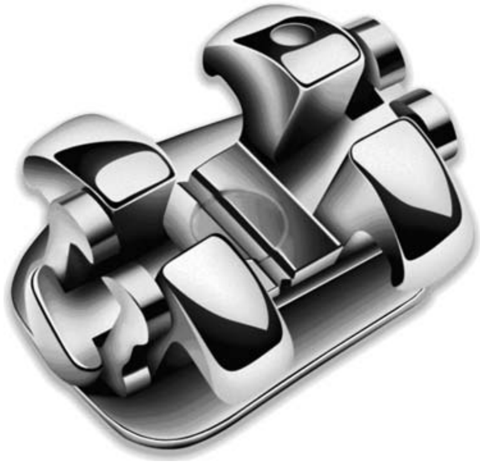

FIGURE 17-14 3M Unitek SmartClip bracket showing the distinctive external spring clips with their jaws through which archwires of all sizes and stiffness must ideally pass very easily and comfortably during archwire changes but never between patient visits.

> System R brackets with their vertical action, have a rigid bracket component to assist the spring in resisting a loss of ligation and are opened and closed vertically and independently of forces from the archwire. It became apparent with wider clinical use that the force required for insertion and removal of thick stainless steel wires from SmartClip brackets was uncomfortably high. Two recent modifications have been aimed at addressing this difficulty by lowering the effective stiffness of the spring clips.

These examples all illustrate the difficulties that have been experienced by manufacturers aiming to meet the requirements of an ideal ligation system. The resulting imperfections in bracket design have undoubtedly slowed the adoption of self-ligation systems by clinicians in previous years. Current self-ligation designs have benefited greatly from previous clinical experience and from advances in the available production techniques such as metal-injection molding, laser forming, and CAD-CAM technology. Although there remain current self-ligating brackets that do not succeed to a sufficient degree in meeting the listed characteristics of an ideal bracket, there are several that perform very well. Technical shortcomings in bracket design and functionality are no longer a reason to avoid self-ligation.

Psychological Factors and Adoption of Self-Ligation

Psychological factors are possibly of equal importance in their influence on the adoption of new technology or new ideas. Most of us have as part of our mindset an innate conservatism and a desire to stay mentally and technically within our comfort zone. We learn a skill that minimizes the deficiencies of our equipment, and then we stick with it because we are comfortable. The more skilled we become in a technique (e.g., bending complex archwires), the more unimpressed by and resistant to a new development (e.g., the straight-wire appliance), which reduces the need for this skill or demands different skills. We also make treatment plans that consciously or otherwise reflect the strengths and weaknesses of our current armamentarium. For example, an anchorage-demanding technique inherently leads to more extractions and more anchorage reinforcement as part of our plans. A second and related factor that previously hindered the rate of adoption of self-ligation has been a lack of widespread appreciation of what low friction, secure archwire engagement, and light forces can achieve in combination. This chapter will examine the evidence for these potential benefits.

AESTHETIC SELF-LIGATING BRACKETS

There have been three approaches to production of a more aesthetic self-ligating bracket. First, there are lingual self-ligating brackets. There are at least three lingual self-ligating brackets currently available. Forestadent has a lingual system, sometimes referred to as the Philippe bracket.[18] The ligation mechanism involves deforming two retaining wings—with a Weingart plier to close and a spatula to open. This mechanism requires considerable care not to damage the enamel if an instrument slips; also, the wings can be hard to open, which can cause detachment of the bracket. Adenta (Adenta GmbH, Gliching, Germany) produces the Evolution bracket, which is essentially a lingual version of the Time bracket produced by the same company; the same applies to In-Ovation L from GAC. Incognito appliances (Lingual Care Inc., 5339 Alpha Road, Suite 150, Dallas, TX) have more recently added an accessory self-retaining slot onto their incisor brackets. Ligation is inherently more difficult with lingual appliances, so an easy form of self-ligation clip or slide that can deliver the advantages of security and low friction are equally or even more valuable in that situation where the interbracket spans are inherently smaller. Combining a successful self-ligation mechanism with the particular lingual demands of low profile, easy archwire insertion, inbuilt bite ramps on some teeth, and narrow bracket width is a demanding task. Further development is needed on this side of the teeth.

On the labial surface, Oyster (Gestenco Inc., P.O. Box 240, Gothenburg, Sweden), OPAL Ultradent Inc., 505W, 1200S, South Jordan), and Damon (partially) are resin brackets (Figure 17-9), while Clarity SL (3M Unitek) and In-Ovation C (GAC) have been produced as ceramic brackets with metal clips. The potential limitations of resin polymers as a category of material for orthodontic brackets are well established. Oyster brackets were originally found to be insufficiently robust. Recently, they have incorporated a metal hinge with the intention of

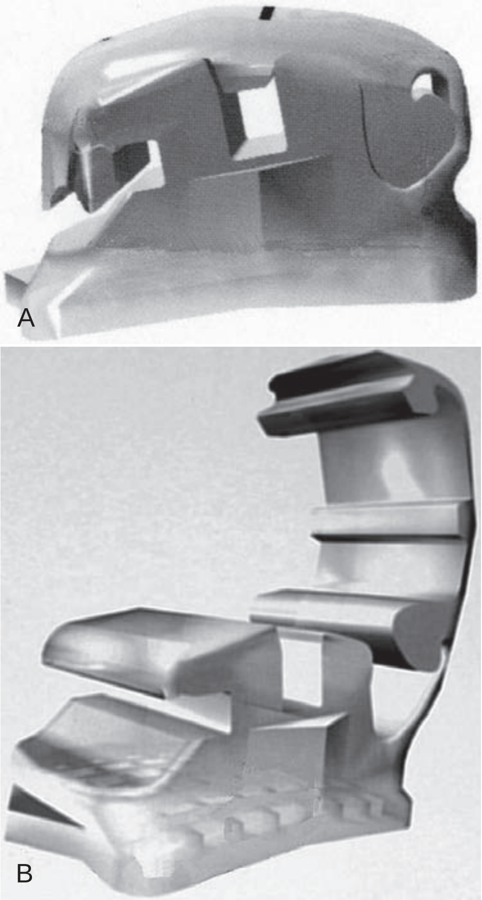

FIGURE 17-15 OPAL bracket closed **(B)** and open **(A)** showing the need for the same material to be rigid in most parts of the bracket, but flexible and still robust at the "hinge" section.

improving this. Opal brackets (Figure 17-15) were introduced later and have an ingenious design to address the challenge of the same material being very flexible in one part of the bracket to create a hinge, while providing as rigid a bracket slot and as reliable a clip as possible. This is not completely successful but represents an imaginative use of polymer material. Good results can certainly be achieved with these brackets, but, as with all resin brackets, rigidity, robustness, and longevity are a challenge. Brackets with a semitransparent labial clip also have to contend with the aesthetic problem of food and debris collecting behind the clip, where they are relatively inaccessible to oral hygiene measures.

The third approach has been to combine ceramic brackets with metal self-ligation clips. Ceramic brackets are long-established in orthodontics with their known benefits and drawbacks. Clarity SL and In-Ovation C are likely to combine these properties with those of the corresponding metal self-ligating brackets already discussed. Further improvement in bracket strength, particularly in relation to torque forces, may come from better ceramic materials or from a stronger design. In-Ovation C has a rhodium-coated clip. It is possible that the optimal combination of self-ligation and aesthetics will come from a breakthrough in the technology for coating metal brackets. The most recent development is a ceramic bracket with a ceramic slide, Damon Clear.

PROPOSED CORE ADVANTAGES OF SELF-LIGATING BRACKETS

When considering the sometimes confusing advantages that have been proposed for self-ligation, it is helpful to divide these into the proposed core advantages and, in a second category, the various proposed consequent advantages that may derive from this core. In the past two decades, a consensus has emerged on the potential core advantages, which can be summarized as:

- Faster archwire removal and ligation
- More certain full archwire engagement
- Less or no chairside assistance for ligation
- Low friction between bracket and archwire

The Speed of Archwire Insertion and Removal

The principle motive when developing the earlier self-ligating brackets was to speed the process of ligation. Maijer and Smith[20] demonstrated a four-fold reduction in ligation time with Speed brackets compared with wire ligation of conventional brackets. Shivapuja and Berger[1] have shown similar results but also that the advantages compared with elastomeric ligation are less dramatic (approximately 1 minute per set of archwires). Voudouris[21] also reported a four-fold reduction in archwire removal/ligation time with prototype Interactwin brackets. A study by Harradine[17] found statistically significant but clinically much more modest savings in ligation/re-ligation time with Damon SL—an average of 24 seconds per archwire removal and replacement. It should, however, be remembered that archwire "ligation" using self-ligating brackets does not require a chairside assistant to speed the process, because self-ligating brackets require no passing of elastomeric or wire ligatures to the operator during ligation. Turnbull and Birnie[22] investigated the difference in time taken to open and close brackets for different archwire groups with Orthos and Damon 2 brackets. The authors found time savings slightly greater than those of Harradine with Damon SL brackets, being 1 second per bracket for opening brackets and 2 seconds per bracket for closing brackets. It was twice as quick to close Damon 2 brackets as to ligate conventional Orthos brackets. For both bracket systems, the time taken to ligate and unligate archwires decreased with increasing archwire size and correspondingly better tooth alignment. The Damon 2 bracket was not the easiest of self-ligating brackets to open and close, and it is very probable that the more recent bracket types from that manufacturer would show much greater savings in time for archwire changes. The increased speed of archwire changes may not seem immediately compelling, but with brackets being ever-easier to open and close, a time-saving of 1 to 2 minutes per archwire change is probably clinically significant. In looking at such studies, it should be remembered that archwire changes with self-ligating brackets were being done by a single-handed operator and were compared with four-handed changing of elastomeric ligatures.

Secure Archwire Engagement

Figure 17-1 has illustrated the loss of full archwire engagement which is commonly seen with elastomeric ligation. An inbuilt metal face to the bracket slot has the potential to ensure full archwire engagement. In the past, several self-ligating designs did not sufficiently fulfill that potential, but many self-ligating brackets now provide reliably secure ligation. However, the thoughtful study by Pandis et al.[23] reveals that it cannot be taken for granted with at least one bracket type that has an active flexible clip that the designed mechanical properties of some self-ligation mechanisms will be sustained throughout treatment.

Friction and Self-Ligation

Very low friction was clearly demonstrated and quantified in many studies in the early 1990s for both Activa and Speed brackets and, indeed, Edgelok. More recent representative studies include that of Kapur et al.[24] who found that with NiTi wires the friction per bracket was 41 *g* with conventional ligation and 15 *g* with Damon brackets whereas with stainless steel wires, these values were 61 *g* and only 3.6 *g*, respectively. Thomas et al.[25] confirmed extremely low friction with Damon brackets compared with both conventional preadjusted and also Tip-Edge brackets, while Time brackets with their active clip produced lesser but still substantial reductions in friction with larger diameter wires. Pizzoni et al.[26] similarly reported that the passive Damon brackets showed lower friction than Speed, which in turn had less friction than conventional brackets. Earlier work that concluded that each elastomeric placed in an “O” configuration produces an average of 50 *g* of frictional force per tooth was more recently supported by Khambay et al.[2] using a method, which gave zero friction for Damon 2 brackets and found mean frictional forces ranging between 43 and 98 *g* (0.43 and 0.98 cN) for various elastomeric/archwire combinations. All of these laboratory studies investigated the situation with essentially passive archwires in well-aligned brackets.

Friction with Active Wires. It is difficult to be certain how accurately any laboratory simulation of friction reproduces the true in vivo situation where other factors, including variable archwire activation and its consequent binding and potential archwire notching, exist. Several studies in the 1990s found that if the wires were active, the friction with self-ligating brackets was not statistically significantly less than with conventionally ligated brackets. Three more recent and excellent reports by Thorstenson and Kusy have investigated aspects of this topic. Thorstenson and Kusy[27] examined the effects of varying active tip (angulation) on the resistance to sliding. They found that angulation beyond the angle at which the archwire first contacts the diagonally opposite corners of the bracket slot causes a similar rate of rise in resistance to sliding for self-ligating (Damon SL) and conventional brackets. However, at all degrees of tip, the Damon brackets produced significantly less resistance to sliding. For example, at a realistic angulation of 6 degrees of tip with an 0.018- × 0.025-inch stainless steel wire, the difference in resistance to sliding was 60 *g* per tooth, which is very probably of clinical significance. The second report[28] compared different self-ligating brackets for resistance to sliding with active angulations. It quantifies a little more closely the lower resistance to sliding with passive self-ligation and points out that low resistance to tooth movement can lead to unanticipated movement as is discussed later in this chapter. The third report[29] examined the same factors with wires of different sizes and in the dry state. The increase in friction when larger wires deflect the clips in active self-ligating brackets is quantified, and the scanning electron micrographs of the different brackets show very clearly the relationship between small and large wires and active clips and passive slides. A more recent study by Matarese et al.[30] is yet another to show that irregularity of the teeth does not prevent self-ligating brackets (Damon 2 in this instance) from producing significantly less friction. Such work strongly supports the view that even though ligation is only one source of the resistance to sliding, self-ligation can reduce this resistance to a clinically significant extent. A systematic review of this question by Ehsani et al.[31] concludes that the case is proved for lower friction with self-ligation with round wires but not for the larger rectangular wires or with active archwires where more evidence is still required. An interesting facet of the study selection for this review is that two of the seminal reports by Thorstenson and Kusy referred to earlier were not mentioned.

Friction In Vivo—Occlusal and Masticatory Forces. A further factor has been investigated in studies by Braun et al.[32] and O’Reilly et al.,[33] who found that various vibrations and displacements of a test jig (to mimic intraoral masticatory forces) can substantially reduce the friction with conventional ligation. This is a valid line of inquiry and an interesting finding, but the question then arises as to how accurately these laboratory studies mimic intraoral masticatory “jiggling” forces. The full interpretation of laboratory friction studies is clearly difficult, and the in vivo situation will show substantial variation. An impressive study by Iwasaki et al.[9] used an intraoral device to produce a combination of tipping and ligation forces and measured the effect of chewing gum on the resulting resistance to sliding. They concluded, “these results refute the hypothesis that masticatory forces consistently and predictably decrease friction.” Clinically—and rather ironically—the low friction with self-ligating brackets seems very evident from the need to place a stop on all archwires to prevent the strong tendency for the archwire to slide through the brackets and traumatize the mucosa distally. Measurement of the variables that influence in vivo friction will remain a challenge, but progress is being made. Although there is still ample scope for more and better studies of this potentially complex field, current evidence supports the view that resistance to sliding in vivo is lowered to a clinically very significant extent with self-ligation—especially with passive self-ligation. Evidence concerning the effects of friction on tooth-moving forces will be discussed later in this chapter.

Secure Ligation and Low Friction as a Combination of Properties

Other bracket types—most notably, Begg brackets—have low friction by virtue of an extremely loose fit between a round archwire and a very narrow bracket, but this is at the cost of making full control of tooth position correspondingly more difficult. Some brackets with an edgewise slot have incorporated shoulders to distance the elastomeric from the archwire and thus reduce friction, but this type of design also produces reduced friction at the expense of reduced control, because the shoulders that hold the ligature away from the archwire increase the slot depth and reduce the tension in the elastomeric. This reduces the control of rotations or of labiolingual tooth position. Elastomeric rings cannot provide and sustain sufficient force to maintain the archwire fully in the slot without also pressing actively on the archwire to an extent that increases friction. Comparison with a molar tube is helpful in this context, because such an attachment is in essence a passive self-ligating bracket with the slide permanently closed. If a convertible molar tube is converted to a bracket by removal of the slot cap or straps, an elastomeric or even a wire ligature can prove very ineffective at preventing rotation of the tooth if it is moved along the wire or used as a source of intermaxillary traction. These ligation methods simultaneously increase friction while attempting to retain full archwire engagement. The challenge of simultaneously combining low friction and good control was very nicely illustrated in an article by Matasa[34] and is reproduced here with his kind permission (Figure 17-16).

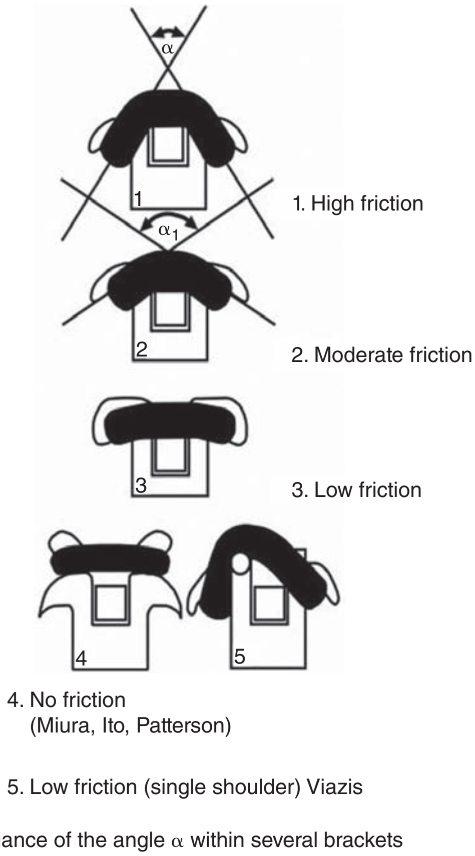

FIGURE 17-16 Illustration from Matasa 2001[34] by kind permission of the author, showing the tradeoff between low friction and good archwire control with conventional ligation.

Matasa investigated “low friction” conventional brackets. He showed that all steps to reduce friction in the design of such brackets, which involved distancing the elastomeric from the archwire, produced a consequent reduction of tooth control. The investigation into three such “low-friction” bracket types by Thorstenson and Kusy[35] also found no evidence that bumps in the floor of the archwire slots reduced resistance to sliding. With tie-wing brackets and conventional ligation, an improvement in friction is usually at the cost of deterioration in control. The combination of very low friction and very secure full archwire engagement in an edgewise-type slot is currently only possible with self-ligating brackets (or with molar tubes) and is likely to be the source of the most beneficial effects of such brackets. This combination enables a tooth to be slid along an archwire with lower and more predictable net forces and yet under good control with almost none of the undesirable rotation of the tooth resulting from a deformable or degradable mode of ligation such as an elastomeric.

The Clinical Significance of Low Friction

Friction between the archwire and bracket must be overcome for the majority of tooth movements to occur. Such movements include vertical leveling, buccolingual alignment, rotation, correction of angulation, opening of space, and any space closure with sliding mechanics. All of these tooth movements involve movement of the bracket relative to the archwire. Frictional forces arising from the method of ligation are one source of the resistance to this relative movement. Correspondingly higher forces must therefore be applied to overcome this resistance, and this has two related potential effects that would be expected to inhibit tooth movement. First, the net effective force is much harder to assess and is more likely to be undesirably higher than levels best suited to create the optimal histologic response. Second, the binding forces are correspondingly higher both between bracket and wire and at the contacts between irregular adjacent teeth. These binding forces also inhibit the required relative movement between bracket and wire. Only a few tooth movements such as space closure with closing loops placed in the space, expansion of a well-aligned arch, and torque (inclination) changes are not influenced by a low-friction method of ligation. One situation in which the combination of low friction and secure full engagement would theoretically be expected to be particularly useful is in the alignment of very irregular teeth, and especially the resolution of severe rotations, where the capacity of the wire to slide through the brackets of the rotated and adjacent teeth significantly facilitates derotation. This relationship between friction and derotation has been classically described and quantified by Koenig and Burstone,[36] where the potential adverse forces from friction were shown to be very large. Low friction should therefore permit more rapid alignment, whereas the secure bracket engagement with self-ligation permits full engagement with severely displaced teeth and full control while the brackets move relative to the archwire.

Figure 17-17 shows the ability of self-ligation to fully engage and maintain engagement of an archwire in a very rotated tooth, while the low friction enables release of binding as the archwire slides through all the brackets in the arch. Modern, low modulus wires with their high elastic limit would be expected to substantially enhance our ability to harness these benefits.

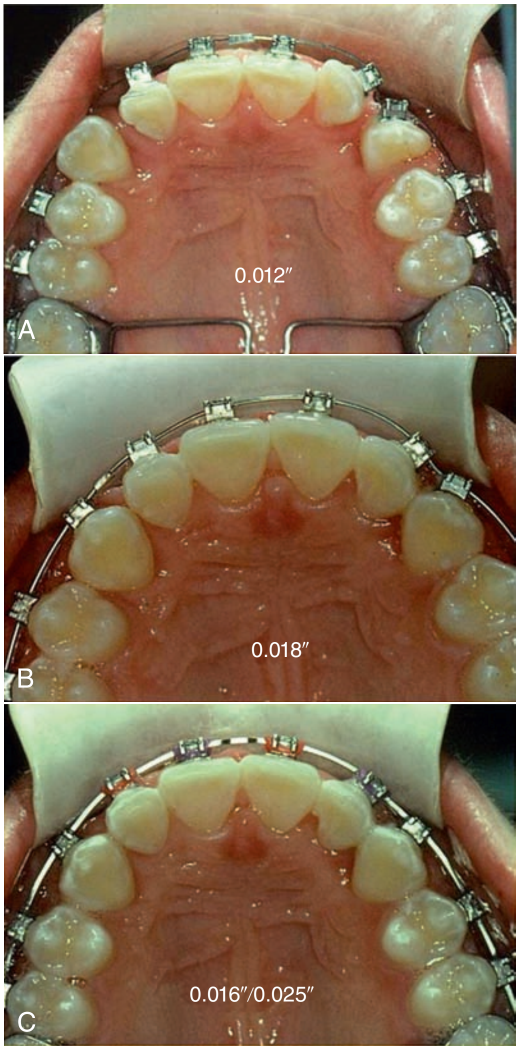

FIGURE 17-17 **A–C,** Three consecutive visits illustrating the effectiveness of rotational alignment, which results from the combination of low friction and good archwire engagement with self-ligation.

SELF-LIGATION AND TREATMENT EFFICIENCY

Several studies have investigated whether these established features of self-ligation in turn result in treatment that is shorter or requires less chairside time. The hypothesis is that lower friction enables more effective relative movement between archwire and bracket and hence more rapid tooth movement while the reliable and full bracket engagement prevents the waste of time regaining tooth control. All published retrospective case control studies[17,37,38] have indeed found greater treatment efficiency. In contrast, the more recent randomized controlled trials (RCTs)[39–44] have almost all failed to show any such effect. This contrast requires some scrutiny.

Possible reasons for differences between findings in treatment efficiency studies are as follows:

- In the retrospective studies that did find an efficiency advantage for self-ligation, the groups may not be adequately matched for type and complexity.
- Some other factor may have been confounding the results (e.g., a different policy on extractions, archwire sequence, or appointment interval with the different brackets).
- The case mix may have been unusual (e.g., more complex cases than average).

With regard to matching of cases, in one of these studies,[17] great care was taken to match the patients in terms of age, type of malocclusion, extraction pattern, and initial PAR (Peer Assessment Rating) score. With the other two studies,[37,38] it is not entirely clear how matched the cases were. This overlaps with the second potential factor—a concurrent change of practice, as well as change of bracket. A clear potential instance would be a change to prescribing fewer extractions when also adopting self-ligating brackets. This was not the case in one of these reports,[17] but in several reported but not published case-comparison series, this was indeed the declared situation, and this raises an interesting philosophical point. If self-ligation through a reduced resistance to sliding facilitates the alignment of adjacent crowded teeth, then it can be argued that it is only sensible to take advantage of a lessening of one of the several reasons for extraction and to change the pattern and extent of extractions. Similar reasoning can be applied to the choice and use of archwires. If particular wires or treatment intervals are more suitable with self-ligation, is it sound scientific investigation to insist on keeping these the same for both brackets types? Although cases should surely be well matched, there is a tenable argument that aspects of treatment mechanics should play to the perceived strengths of each type of bracket. The differences found by Tagawa[38] are the most pronounced, and it is probable that several such additional factors were at play. Regarding case mix, this may well be a factor because it is probable that any actual advantages of self-ligation would be more pronounced in certain cases. The cases in one report[17] were substantially more complex than average, reflecting the particular tertiary referral setting of that study.

In the RCTs that have almost all failed to find a difference in treatment efficiency, several factors are pertinent.

None has yet reported on completed cases. Potential differences in treatment efficiency may be partially related to archwire control in the later stages of treatment. In the example in Figure 17-1, it is highly likely that additional time and archwire changes were required to regain the rotational tooth control, which has been lost with conventional elastomeric ligation.

The study on closure of extraction spaces[41] primarily involved the archwire sliding only through molar tubes, which therefore applied equally in both groups.

As discussed earlier, factors such as casemix, appointment interval, and archwire sequence may not have been optimized for the self-ligating brackets but have been chosen to be identical regardless of bracket type.

RCTs of orthodontic appliance systems are susceptible to the involvement of clinicians who are unfamiliar with one of the appliances. This may be a factor in these studies.

The "Nickel-Titanium" Dilemma

This name refers to the fact that it is almost universally accepted that nickel-titanium wires are superior for tooth alignment compared with their stainless steel predecessors. However, none of the studies that investigated that hypothesis demonstrated its truth. Similarly, none of the relevant studies demonstrated that straight-wire appliances were superior to plain edgewise, but the former are overwhelmingly preferred for reasons that are regarded by clinicians as being self-evident and in no need of the highest order of scientific proof.

The question of treatment efficiency remains open. The current evidence strongly suggests that there is not a substantial, blanket enhancement of treatment efficiency that is generally applicable in all cases and situations. The retrospective studies would, however, suggest that if investigators and funding persist (and they did not with nickel-titanium wires or the straight-wire appliance), it may eventually be shown that in some malocclusions treated with particular brackets and wires and treatment intervals, self-ligation is more efficient. Currently, the only clearly substantiated gain in efficiency results from faster ligation and the lack of need for assistance with ligation.

ACTIVE CLIPS AND PASSIVE SLIDES

This choice of design is an issue that has attracted assertive debate.[45] It is therefore worth a fairly detailed consideration.

In Box 17-1, Speed, In-Ovation, and Forestadent Quick brackets are examples of brackets that have a spring clip, which encroaches on the slot from the labial aspect, potentially generating an additional force on the tooth. With some of the force being stored in the deflection of the spring clip, these brackets are referred to as active clips. In contrast, passive brackets have a slide that closes to create a rigid labial surface to the slot with no intention or ability to invade the slot and store force by deflection of a metal clip. Damon, Smartclip, Lancer Pacific Praxis Glide, Class One/Ortho Organisers Carrière LX, American Orthodontics Vision LP, Ortho Technology Lotus, and OrthoClassic Axis are examples of passive systems. Some literature has occasionally contained statements to the effect that the term "passive" is inappropriate because there must be force between the bracket and the wire for teeth to move. This is an unhelpful and possibly disingenuous interpretation of the word "passive" when used in this context, and the term "passive" is entirely comprehensible when defined as done earlier, meaning a bracket analogous to a molar tube.

An active clip can store some of the applied force in the clip as well as in the wire. The intended benefit is that in general terms a given wire will have its range of labiolingual action extended and produce more alignment than would a passive slide with the same wire. This needs more detailed consideration. It is perhaps helpful to think of the situation with three different wire sizes.

Thin Aligning Wires Smaller Than 0.018-Inch Diameter

The potentially active clip will be passive and irrelevant unless the tooth (or part of the tooth if it is rotate) is sufficiently lingually placed in relation to a neighboring tooth that the wire touches the clip. In that situation, a higher total force will usually be applied to the tooth in comparison to a passive slide. Even if there is no significant clip deflection, there is still a force on the wire that would not exist with a passive clip because the active clip effectively reduces the slot depth from 0.028 inch to approximately 0.018 inch, either immediately—if the clip is not deflected—or as the wire goes passive if it is deflected. For teeth that were initially placed lingual to their neighbors, the active clip can bring the tooth more labially (up to a maximum of 0.028 − 0.018 = 0.010 inch) with a given wire. These values are slightly complicated by the fact that the active clip does not reduce the slot depth to the same extent over the whole height of the slot—all active clips impinge into the slot more at the gingival end than at the occlusal. This is well visualized in the illustrations in Thorstenson and Kusy.[29] This asymmetry would make a difference with small-diameter wires depending on the relative vertical positions of neighboring teeth. The effect of having an active clip at this early stage of treatment can be thought of as having a potentially shallower bracket slot. This will frequently produce higher forces and correspondingly higher friction with a given wire but a potential maximum extra 0.010 inch of labial movement of some teeth for a given small-diameter wire. This value is approximate for the reasons given earlier.

Wires Larger Than 0.018-Inch Diameter

The active clip will place a continuous lingually directed force on the wire even when the wire itself has become passive. On teeth that are in whole or in part lingual to a neighboring tooth, the active clip will again bring the tooth (or part of the tooth if rotated) to a fractionally more labial position than would have been the case with a passive slide. The maximum difference will be the difference between the labiolingual dimension of the wire and 0.028 inch. For a typical 0.016- × 0.022-inch intermediate wire, this would give a maximum difference of 0.006 inch; 0.016- × 0.025- or 0.014- × 0.025-inch nickel-titanium wires are recommended as the intermediate aligning wire for passive brackets, and this wire reduces this potential difference to a clinically insignificant 0.003 inch. Lingually placed teeth would have a higher initial force with an active clip and wires of this intermediate size. With an active clip, an active lingually directed friction force will remain on the wire even when it is passive.

Thick Rectangular Wires

An active clip will probably make a labiolingual difference in tooth position of 0.003 inch or less, which is clinically very small. The suggestion that continued lingually directed force on the wire from an active clip (or from a conventional ligature) will cause additional torque from an undersized wire is interesting. The general question of self-ligation and torque effectiveness is addressed later in this chapter. In relation to active clips or passive slides, the relevant study is by Badawi et al.,[46] who demonstrated that the lingually directed force from an active clip does indeed contribute to torquing capacity by reducing the “slop” or “play” angle at which sufficient force is generated to influence third order tooth position.

Aging of Spring Clips

Finally, there are the questions of robustness, security of ligation, and ease of use. Is a clip, which is designed to flex, also more prone to breakage or permanent deformation or to inadvertent opening or closing? This question has not yet been investigated sufficiently, but one pertinent piece of work has been conducted by Pandis et al.,[23] who retrieved spring clips from Speed and In-Ovation R brackets following treatment and compared the stiffness and range of action of these spring clips with those of unused spring clips. The two types of bracket had spring clips of very different initial stiffness and also differed in their performance during treatment. The Speed clips changed insignificantly in their performance, but the In-Ovation clips lost an average of 50% of their stiffness during the treatment. This change in properties is sufficient to possibly have biomechanical consequences of clinical significance.

Active or Passive—Conclusion

Alignment. It is probable that with an active clip, initial alignment is more complete for a wire of given size to an extent that is potentially clinically useful. With modern low modulus wires, it is possible to sequentially insert thicker wires into a bracket with a passive slide and arrive at the working archwire size after a similar number of visits.

Friction. Overall, an active clip will generate higher archwire forces and higher resistance to tooth movement. The increased clearance between a given wire and a passive slide will generate lower forces and may facilitate dissipation of the adverse binding forces and the ability of teeth to push each other aside as they align. This may also lead to qualitative differences in the direction and amount of tooth movement; this will be discussed later.

Robustness and Ease of Use. In any specific bracket these factors are frequently related to the type of clip or slide whether active or passive.

SELF-LIGATION AND PATIENT COMFORT

There have been a number of studies investigating the hypothesis that self-ligation produces less patient discomfort than conventional brackets and ligation.[38,41,47–50]

Tagawa[38] found a substantial reduction in reported pain with Damon SL brackets and Pringle et al.[48] found significantly less pain with Damon 3 brackets. However, other authors[41,47] have found no difference in the first week or month of treatment and one study[47] found that the actual process of archwire changes with SmartClip brackets was reported as significantly more uncomfortable than with conventional ligation. The distinctive mode of action of Smartclip brackets has been noted earlier. A very interesting report by Yamaguchi et al.[50] examined the question via a different marker of the inflammation and associated pain resulting from orthodontic forces. They measured levels of the neuropeptidase substance P in gingival crevicular fluid. They found that treatment with Damon brackets significantly lowered the levels of this marker of pain and inflammation compared with conventional ligation at 24 hours after archwire placement. The hypothesis that self-ligation may be less painful is based on the assumption that forces on the teeth will be lower. This is not necessarily the case, being particularly sensitive to the choice of archwire. Force levels will be discussed later in this chapter.

SELF-LIGATION AND EFFECTIVENESS OF TORQUE CONTROL

The hypothesis has been advanced that torque control is more difficult with self-ligating brackets and perhaps particularly with passive brackets. This proposal is probably based on the belief that the labiolingual forces between the base of the bracket and a ligature system are a significant additional source of force couple, adding to the couple between the upper and lower bracket walls that exists with all brackets. This situation is not straightforward and is probably influenced by several factors.

Conventional ligation can apply a high labiolingual force but can also permit incomplete archwire engagement. If this is the case, then the effective “play” or “slop” angle between archwire and bracket walls is significantly increased and torque effectiveness correspondingly reduced.

An active self-ligation clip invades the bracket slot and might be expected to place an effective torque force at a smaller “slop” angle than a passive bracket. This has been investigated by Badawi et al.,[46] who found that with an In-Ovation bracket, the active clip provides sufficient force to reduce the effective “slop” by 7 degrees with a 0.019- × 0.025-inch wire compared with a passive self-ligating bracket. This difference would be expected to sometimes result in detectable differences in achieved torque control.

In routine clinical practice, the appropriate choice of bracket prescriptions and archwires might reduce this potential factor to an insignificant level. This view would be supported by the study by Pandis et al.,[51] who, in a study of 105 patients, found no difference in incisor torque effectiveness when comparing Damon 2 and conventionally ligated brackets. The more recently increased choice of torque prescriptions in self-ligating brackets would be expected to strengthen this conclusion.

This author has experienced no difficulty obtaining torque control with either active or passive self-ligating brackets. The only disadvantage of lower friction is the need to prevent unwanted mesiodistal movement of the wire through the brackets, which leads to wire pokes, or movement of teeth along the wire, which leads to unwanted spaces. If a clinician feels strongly that conventional ligation is a benefit in torque control, then it is open to him or her to add conventional ligation on the desired teeth using the tie-wings that the majority of self-ligating brackets possess. It is worth noting that there has been no detectable pressure for tie-wings to be added to all molar tubes (which are passive self-ligating brackets) in order to increase molar torque control through conventional ligation.

FURTHER CURRENT HYPOTHESES ABOUT SELF-LIGATION

The core advantages of faster ligation, better archwire control, and lower resistance to sliding can and should continue to benefit from scientific study on points of detail, but they can at this stage be safely regarded as sufficiently proved. The further hypotheses concerning more efficient treatment, more comfortable treatment, and more healthy treatment are all receiving appropriate investigation but remain hypotheses. There remains a third category of proposed advantages that can be described as proposed qualitative differences in tooth alignment. Many clinicians who use self-ligating brackets believe that when combined with light round wires, they facilitate the alignment of crowded teeth. However, some clinicians have additionally proposed that the teeth align in a qualitatively different manner, producing less incisor proclination and more lateral expansion than conventional ligation. In this respect, the following qualitative differences have been proposed with self-ligation:

- Less incisor proclination for alignment of a given amount of crowding
- Wider arches, which may be more aesthetic
- Wider arches, which have better preserved bone levels and consequent periodontal health than those resulting from more rapid and forceful expansion
- Wider arches, which may be more stable
- Less need for extractions
- Easier Class II correction through a “lip-bumper” effect

Many of these proposals have been set out and illustrated with case examples and medical computed tomography scans.[52] A well-known case example (Figure 17-18)

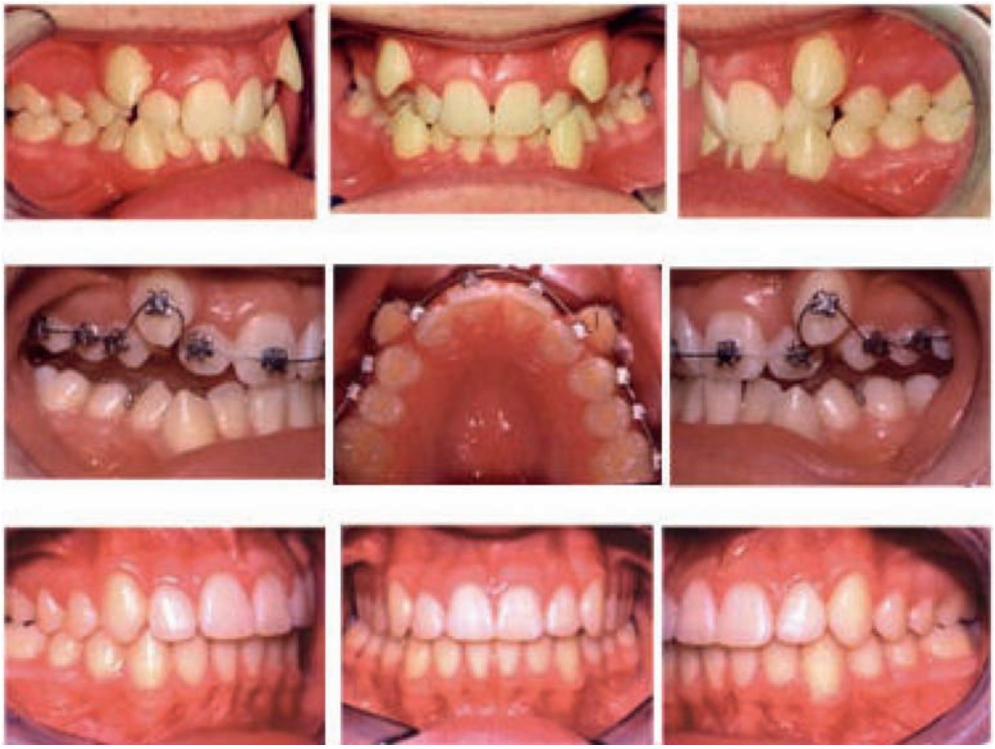

FIGURE 17-18 Class 2 Division 2 malocclusion treated with Damon 2 passive self-ligating brackets and without extractions. By kind permission of Dr. Damon. The buccally placed canines and palatally inclined premolars and molars at the start of treatment are evident.

that helps to illustrate several of these proposals is reproduced by kind permission of Dr. Dwight Damon. In this, Class II Division 2 malocclusion, the very crowded arches have been aligned without extractions. The expectation would be that this would result in very pronounced incisor proclination. In fact, the incisors moved labially less than 3 mm, but the posterior arch expansion was much greater than might have been anticipated (Figure 17-19).

This pattern of tooth movement has been attributed by some clinicians to a qualitatively different interaction of forces. In particular, it is suggested that the applied forces are so low that the lips can compete with orthodontic forces and restrain labial movement of the teeth. Additionally, it has been proposed that the tongue position may alter in response to this expansion and possibly assist in the tooth movement or in its subsequent stability. This author suggests that the expansion in this case example may well be entirely explicable by the balance of forces between the teeth and particularly the lateral forces arising from the bucally placed canines and acting upon palatally inclined premolars, but the ratio of proclination to expansion remains surprisingly low in the light of experience with conventional ligation. The force levels with self-ligation will be considered later, but first it is helpful to look at two consecutive visits in a case reproduced by kind permission of Dr. David Birnie (Figure 17-20).

It can be seen that the incisors have extravagantly (although temporarily in this instance) proclined. A major factor must surely be the high resistance to sliding produced by the figure-of-8 elastomeric ligatures on the premolars, which has prevented the excess wire sliding distally as the canines moved buccally. This author proposes that self-ligation does not necessarily result in lower forces but can generate a higher percentage of desirable force and a lower percentage of unwanted forces, and it is this difference that may significantly alter the resulting tooth positions. In the case shown in Figure 17-20, the unwanted force is the high and persistent proclining force on the incisors that has arisen because of the friction from the elastomeric premolar ligatures.

Figure 17-21 shows alignment in a Class III patient who at an older age underwent the planned orthognathic surgery. The intention in aligning the upper arch was to do so without significantly proclining the upper incisors and hence compensating for the Class III skeletal pattern. The untreated lower incisors act as a reference to demonstrate that there has indeed been very little upper incisor proclination. The initial proclining forces on the incisors must have been very significant and indeed all the higher for the full engagement that self-ligation has enabled and maintained on the lateral incisors. It is

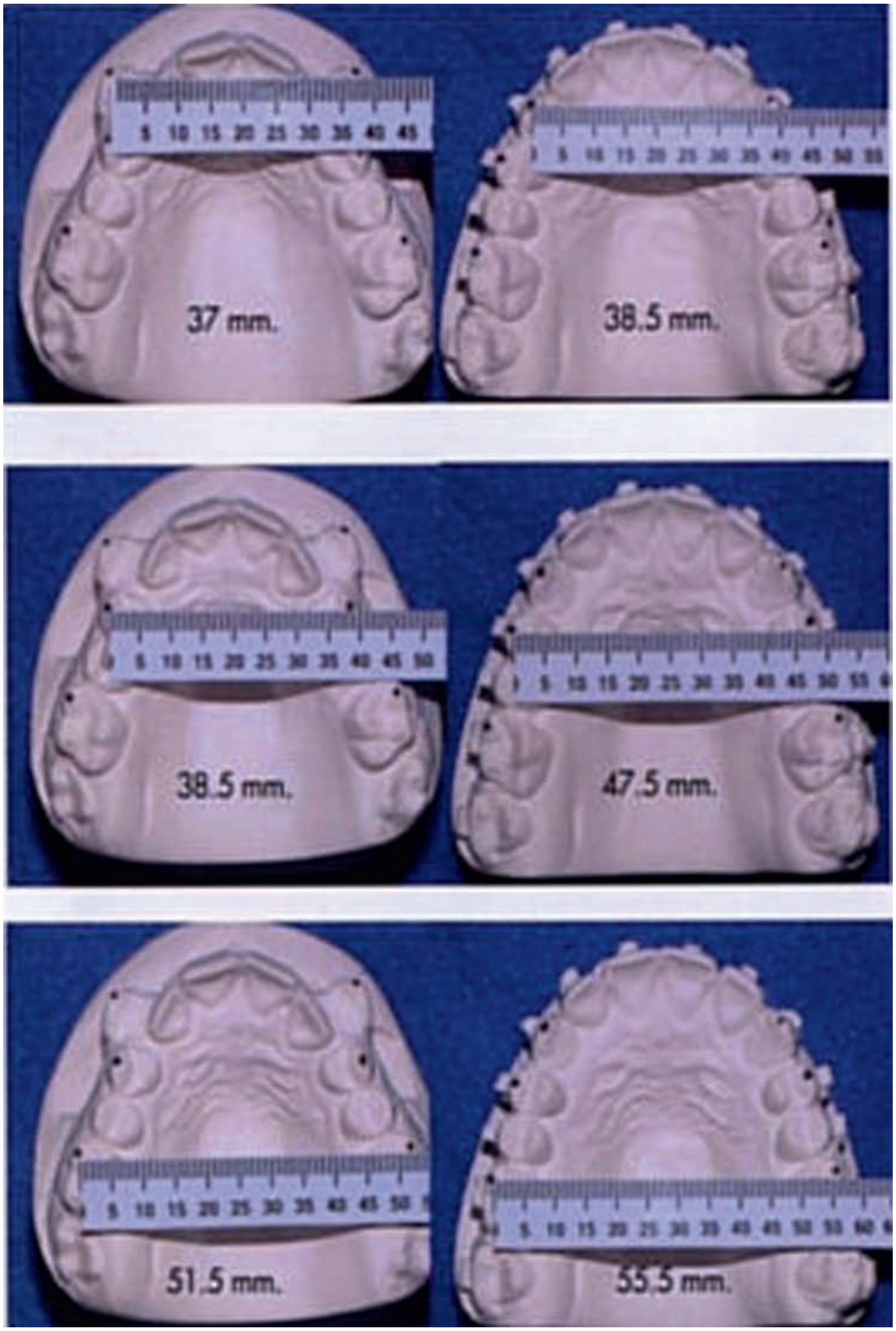

FIGURE 17-19 Arch width changes during treatment of the case presented in Figure 17-18. There is minimal expansion of the canines but substantial uprighting and expansion of the premolars and molars.

suggested that the ability of the wire to release from the binding in the canine and the premolar as soon as tooth movement begins has enabled the alignment to occur with the wire sliding distally rather than by incisor proclination. The hypothesis of a qualitative difference in the pattern of tooth movement would seem to have enough credibility to justify more rigorous investigation.

FORCE LEVELS WITH SELF-LIGATION AND CONVENTIONAL LIGATION

The potential for measurement of these forces has been advanced substantially by the development by Dr. Badawi and co-workers at the University of Alberta of a force measurement system of impressive power, realism, and versatility (Figure 17-22).

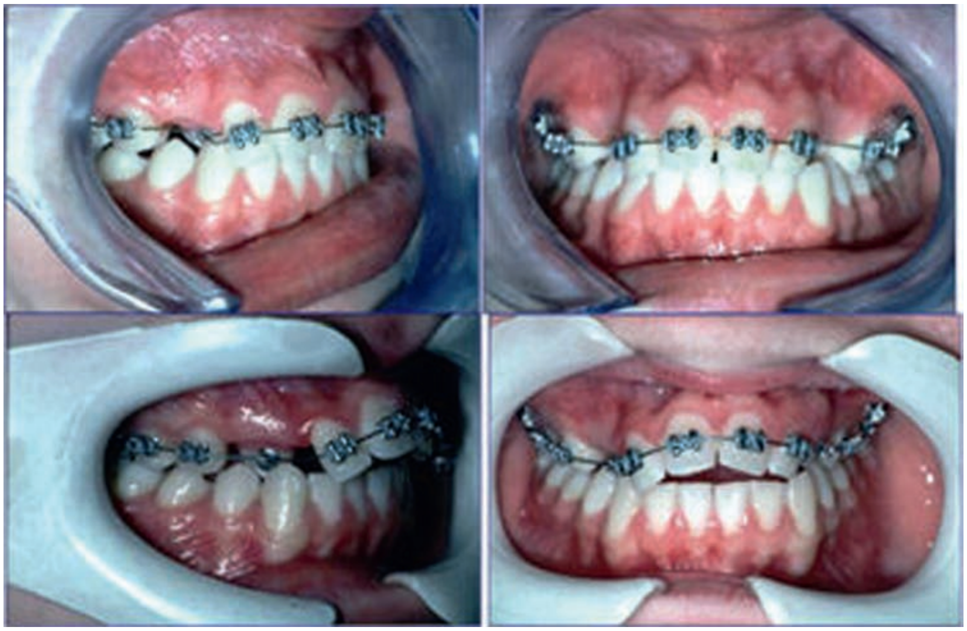

FIGURE 17-20 Proclination of upper incisors between consecutive appointments associated with figure-of-eight elastomeric ligation on all teeth except the palatal canines; 0.014-inch archwire.

This design of this device has been described and its errors quantified.[19] This apparatus can realistically simulate almost any arch alignment with any combination of brackets and archwires and can measure and simultaneously graphically display all the resultant forces. Data from this study[19] investigates levels of force available to move malaligned teeth and also the levels of unwanted forces resisting this alignment. These early results demonstrate the much higher proportion of unwanted forces with conventional brackets and also significantly higher unwanted forces with active self-ligation when compared with a passive system.

The higher percentage of desirable force that can result from self-ligation is neatly and simply shown in the excellent study by Baccetti et al.[53] The simple but clever aspect of this laboratory use of a strain gauge is that instead of the familiar measuring of force required to draw a wire through an irregular alignment of brackets (i.e., the unwanted resistance to movement), it measures the desired net aligning force remaining on a displaced tooth. The study shows that with conventional ligation a tooth displaced 3 mm vertically from the line of the arch with an 0.012-inch wire has only 50 *g* of net aligning force available compared with more than 90 *g* with the several types of self-ligating brackets that were tested. With 4.5 mm of displacement, there is no remaining force available for alignment of the displaced tooth with conventional brackets but over 80 *g* remains with self-ligating brackets despite the binding at each corner of the brackets.

These more recent studies support this authors' view that self-ligation is not inherently and in all situations a low force system. Indeed the lack of friction raises the net force on irregular teeth with a given wire. However, a point of significant clinical relevance is that in an irregular arch with a suitably low-force wire, self-ligation can still produce effective tooth moving forces[53] and these forces are combined with low unwanted forces on adjacent teeth. It is these unwanted forces that resist or may adversely change the direction of tooth movement. This relationship requires further experimental confirmation but is a distinct feature of self-ligation that is less obvious than the combination of low friction and good control but perhaps of equal significance. The role of forces arising from the soft tissues will remain less amenable to realistic measurement, but it may not be necessary to propose any significant change in, for example, tongue behavior in order to explain tooth movements that at first encounter may prompt such suggestions. The exploration of this area of conjecture has some similarities to the long journey that eventually led to our sound understanding and quantification of the mode of action of functional appliances.

DOES SELF-LIGATION REDUCE THE NEED FOR EXTRACTIONS?

A scrutiny of this claim benefits from some dissection of the indications for extraction, which can be categorized as follows:

- Space for alignment of crowded teeth
- Profile improvement
- Interarch relationship
    - Correction of overjet
    - Correction of overbite

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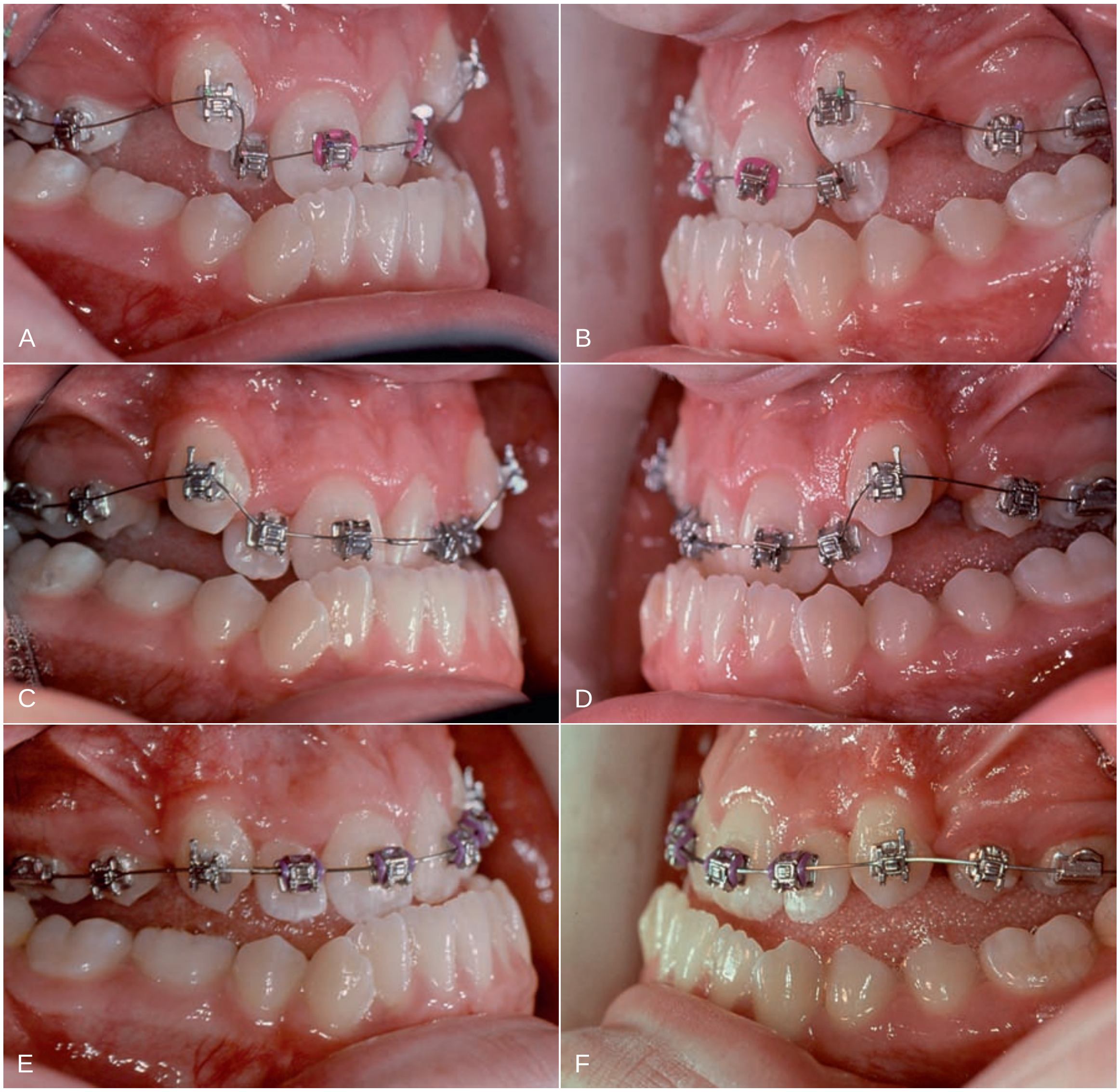

FIGURE 17-21 Three consecutive visits at 8-week intervals. Damon 2 passive brackets with initial 0.012-inch wires were left for 16 weeks and replaced by 0.014- × 0.025-inch wires at the third visit **(E, F).** The lack of significant central incisor intrusion or proclination is evident. The elastomeric ligatures on some teeth were for decoration at the patient's request and were deliberately placed on teeth anterior to the crowding, where no sliding of the archwire relative to the bracket was required. (The author no longer receives requests for this decoration!)

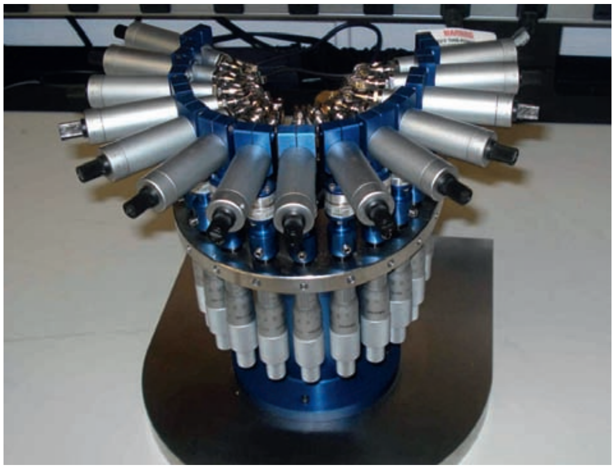

FIGURE 17-22 The Orthodontic Simulator (OSIM) developed at the University of Alberta. Multiaxis force and moment transducers are attached to all 14 teeth and micrometer screws permit quantified and incremental movement in the vertical and horizontal planes. *(By kind permission of Dr. Hisham Badawi.)*

CASE STUDY 17-1

A Severely Crowded Lower Arch Treated without Extraction

Dr. David Birnie

Patient 1 presented at 14 years 0 months with moderate upper arch crowding and severe lower arch crowding. His facial appearance was prepubescent, he did not seem to have entered his pubertal growth spurt, and it was thought that significant nasal tip and chin growth would occur during his teenage years. He has a left unilateral crossbite. The lower right central incisor has a long clinical crown (Figure 17-23, *A–H*). When looking at the severe lower arch crowding, it should be noted that he still retains lower deciduous second molars and that the first premolars are in a Class I relationship. All permanent teeth were present on the dental pantomogram except for the upper third molars. His oral hygiene was good, although still capable of improvement. Treatment was initiated with light 0.014-inch wires and lightly activated coilspring with the most ectopic instanding teeth being lightly engaged from an early stage in order to act as a restraint on overall incisor proclination. Figure 17-24, *A–E,* shows treatment progress after seven months of treatment. Alignment has almost been achieved in the upper arch, but there is still insufficient space for the lower left lateral incisor. The lower deciduous molars are still present. No crossbite correction has yet taken place; note that the right second molars, which are just visible, are not in crossbite. Figure 17-25, *A–E*, shows the situation 15 months into treatment. Alignment within the arches has been achieved, but crossbite correction has not yet taken place. Figure 17-26, *A–E*, was taken 25 months into treatment. The second molars were bonded 16 months into treatment, and crossbite correction then occurred spontaneously without the need for auxiliary appliances or cross elastics. Once stainless steel archwires were placed, the upper archwire was expanded and the lower contracted to ensure maximal correction. Figure 17-27 shows the posttreatment cephalometric radiograph and the superimpositions. There has been no significant change in skeletal pattern. The lower incisors have proclined by 10 degrees with approximately 3 mm of labial movement, while the upper incisors are at their pretreatment position and inclination. Despite the lack of upper incisor retraction, the nasolabial angle has become more obtuse and the upper lip is substantially farther from the E line, reflecting the substantial nasal growth. The arch widths show increases in varying amounts. The 10-mm increase in lower intercanine width reflects the inevitable increase if all such crowded incisors are to be accommodated. The increase in lower intercanine width would have had to be substantial even had premolars been extracted and the canines moved distally as well as buccally. The upper arch expansion additionally reflects the correction of the posterior crossbites. Figure 17-28, *A–I,* is taken 3 years after the end of active treatment. The clinical crown heights of the lower incisors have equalized and continue to show no recession. In addition to the fixed retainers, the patient wears vacuum formed retainers at night. Despite the significant arch expansion, there is no undesirable buccal inclination of the upper incisor crowns.

This case illustrates the ability of passive self-ligation with light wires and gentle activation to accommodate extremely crowded teeth without extractions and perhaps with less incisor proclination that might have been anticipated. The periodontium appears to be remaining healthy. With regard to stability, almost all clinicians would place a fixed lower lingual retainer in this situation; however, the teeth had been aligned. A clinician with different treatment planning priorities may equally have chosen to accommodate the crowded teeth and correct the overjet by means of extractions. This would have had different consequences for the width and prominence of the dentition within the adult face. The proposal is that without the biomechanical properties of self-ligating brackets, a nonextraction treatment plan would have been much less practicable and therefore not an available option.

Profile

If research confirms that self-ligation can align teeth with less incisor proclination and relatively more lateral expansion, then this would reduce the need for extractions to prevent or correct a profile that is too full. At present this remains an interesting and plausible hypothesis.

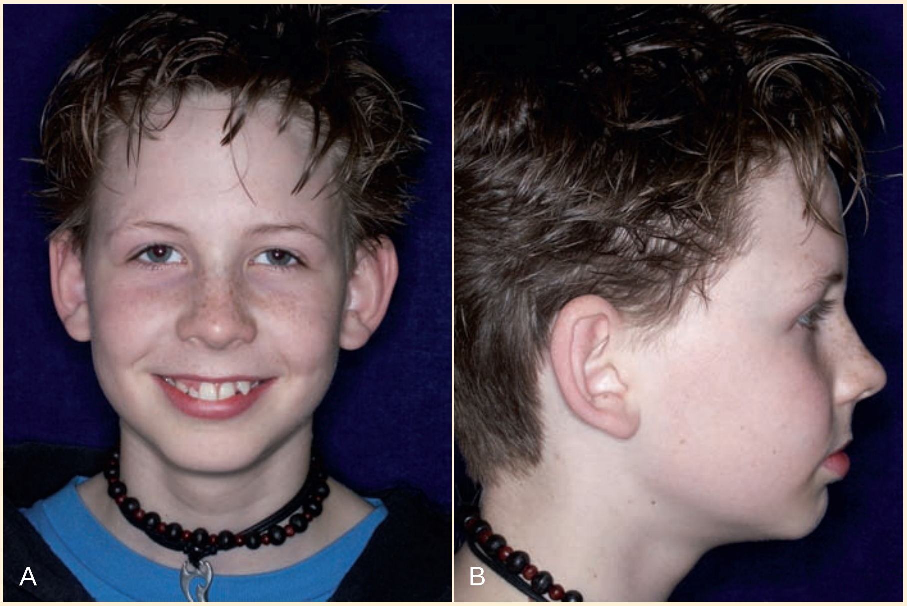

FIGURE 17-23 A–H, Pretreatment records of patient 1 (Case Study 17-1), aged 14 years but still prepubertal.

CASE STUDY 17-1 A SEVERELY CROWDED LOWER ARCH TREATED WITHOUT EXTRACTION—Cont'd

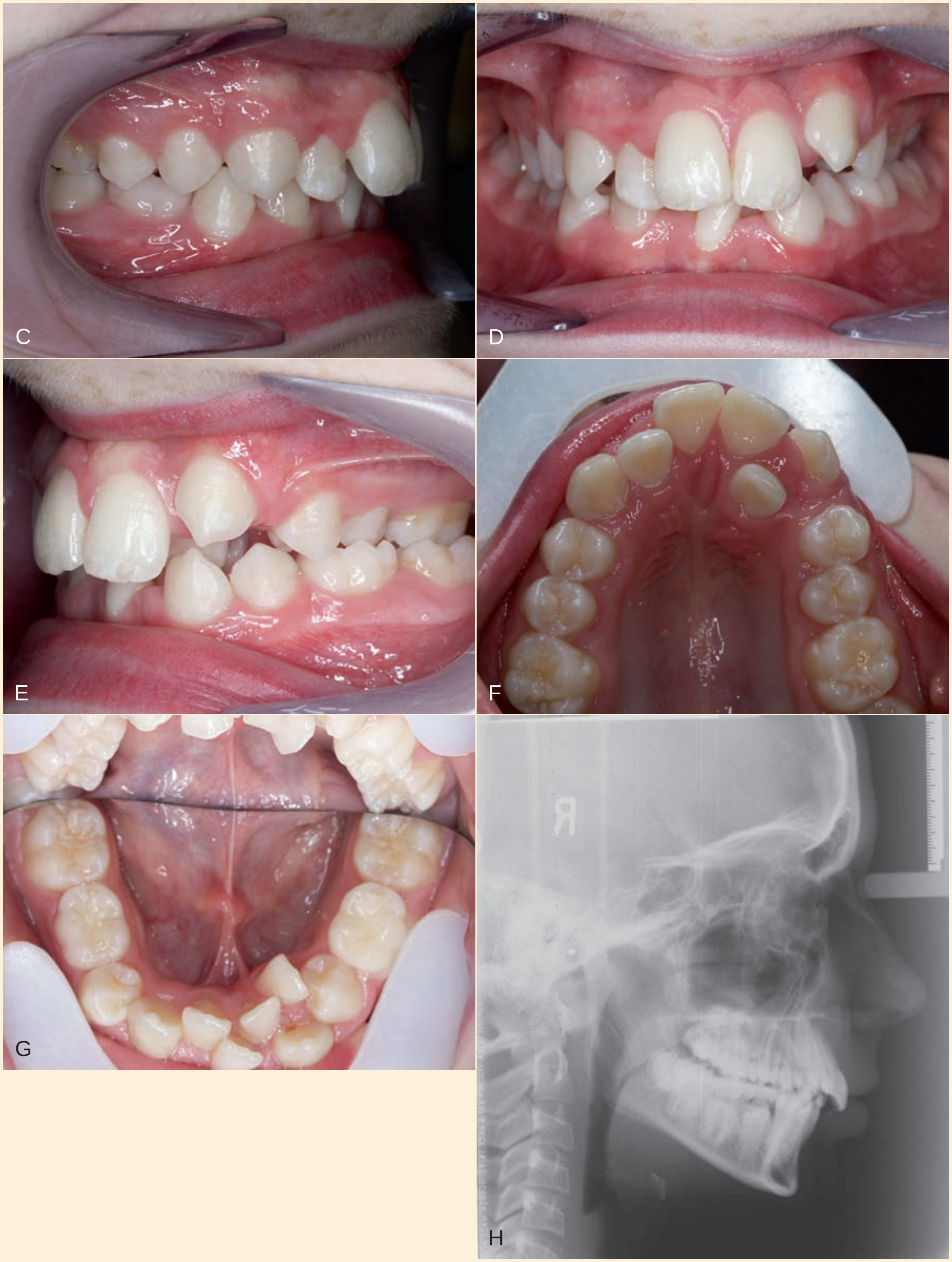

FIGURE 17-23, cont'd

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CASE STUDY 17-1 A SEVERELY CROWDED LOWER ARCH TREATED WITHOUT EXTRACTION—Cont'd

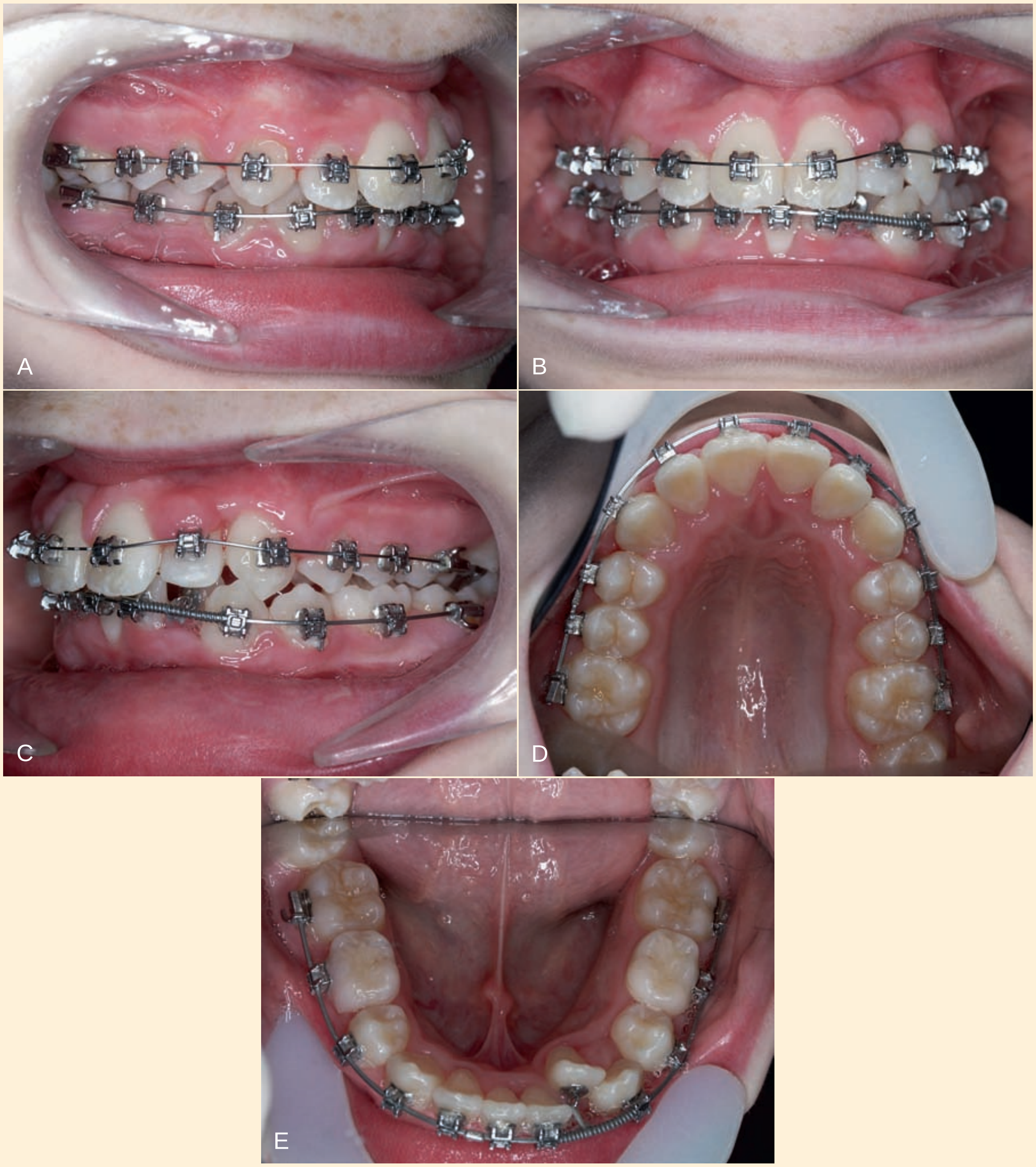

FIGURE 17-24 **A–E,** Progress records after 7 months of treatment with light aligning wires.

CASE STUDY 17-1

A SEVERELY CROWDED LOWER ARCH TREATED WITHOUT EXTRACTION—Cont'd

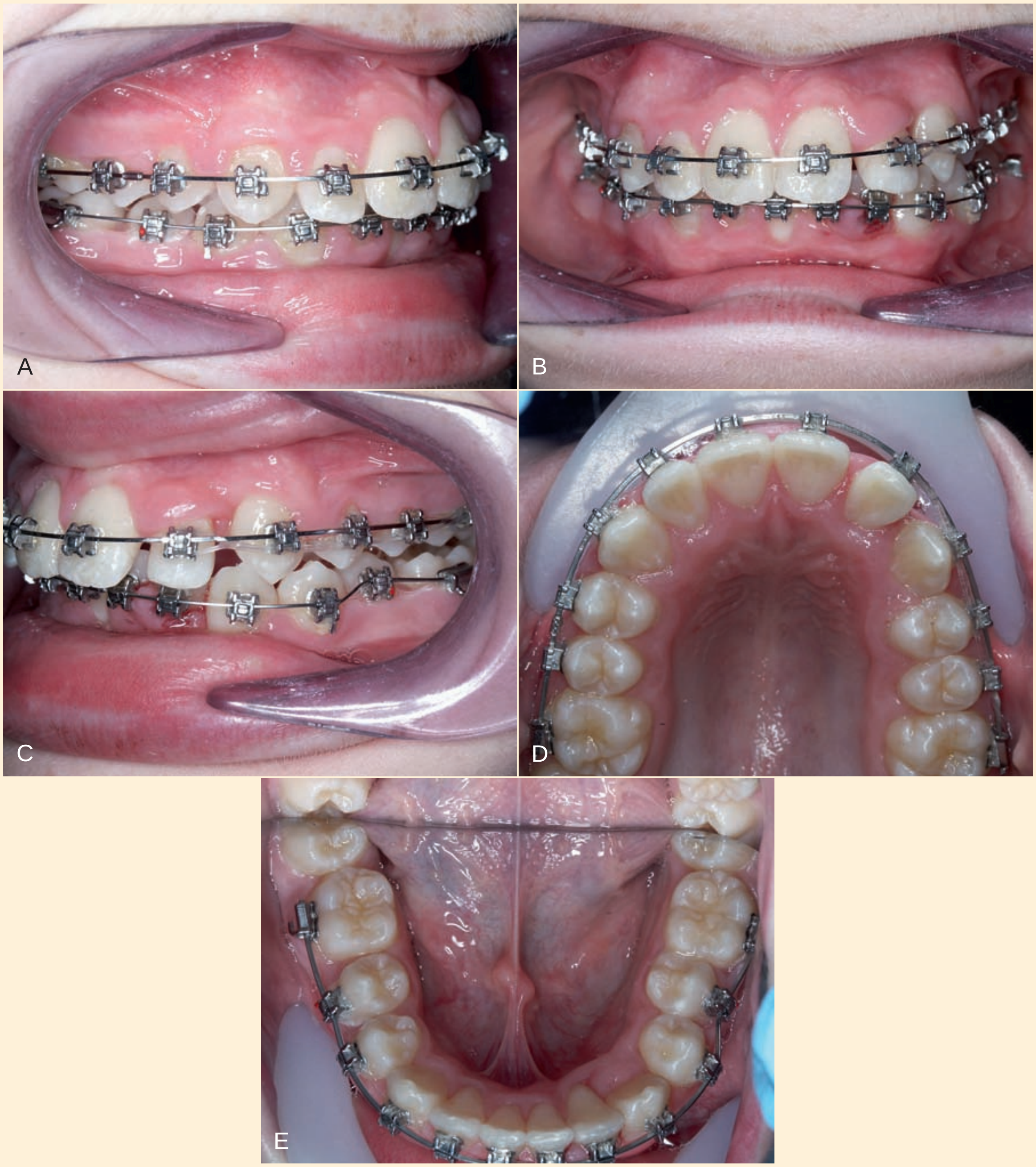

FIGURE 17-25 A–E, Progress records for patient 1 (Case Study 17-1) after 15 months. Alignment is almost achieved, but torque and crossbite corrections are still required.

Continued

CASE STUDY 17-1

A SEVERELY CROWDED LOWER ARCH TREATED WITHOUT EXTRACTION—Cont'd

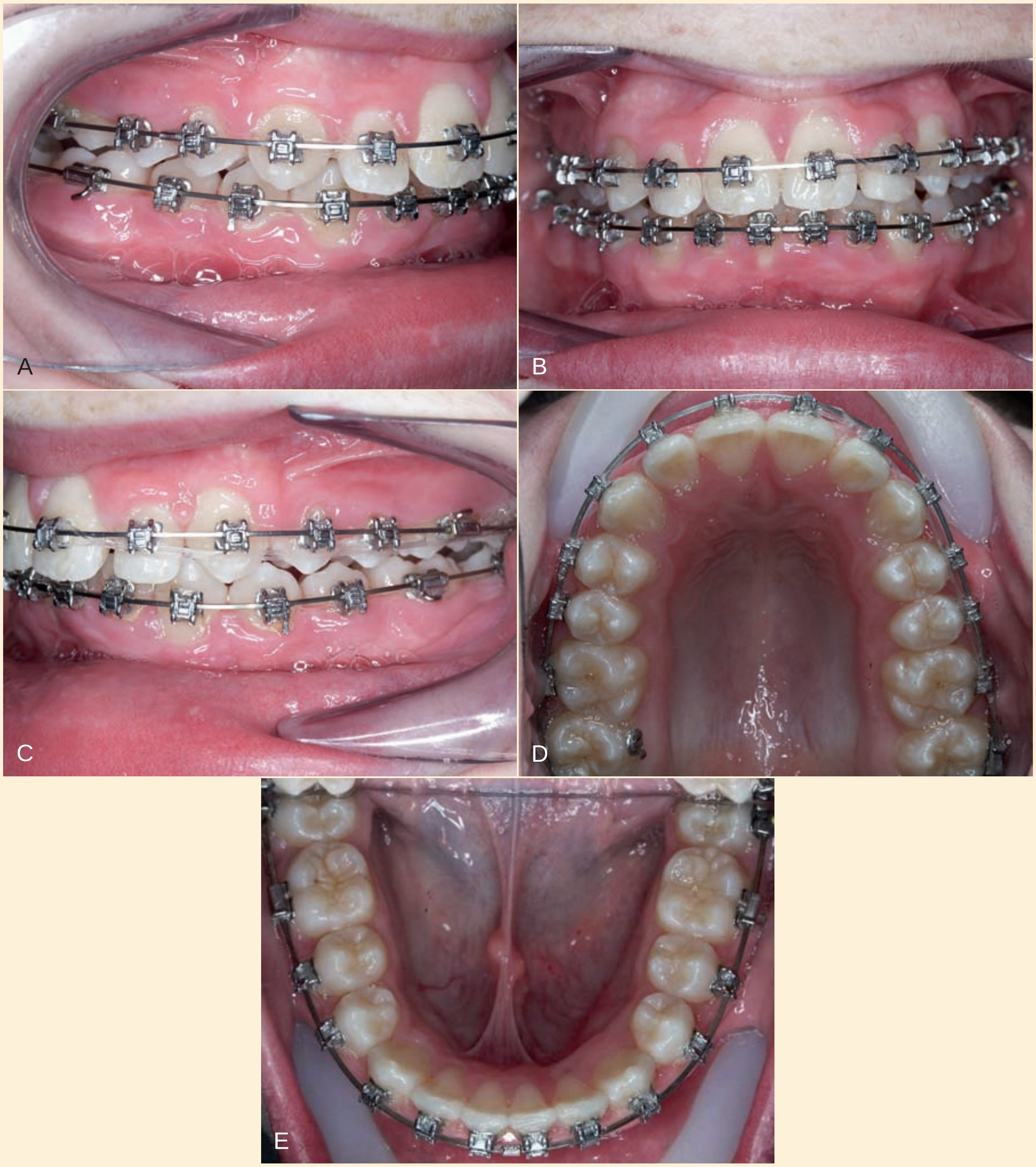

FIGURE 17-26 **A–E,** Patient 1 (Case Study 17-1) after 25 months of treatment.

CASE STUDY 17-1 **A SEVERELY CROWDED LOWER ARCH TREATED WITHOUT EXTRACTION—Cont'd**

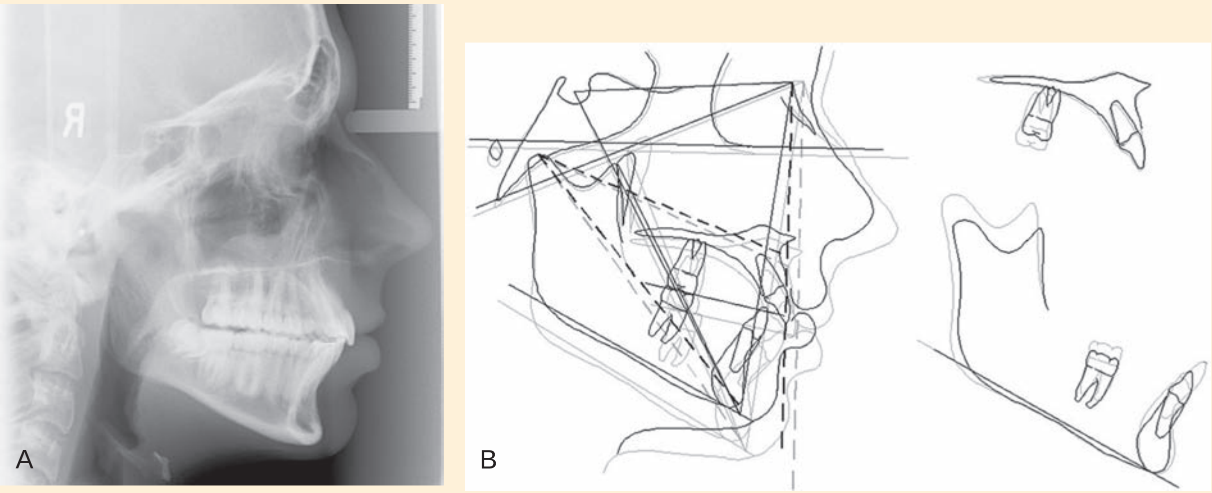

FIGURE 17-27 **A, B,** Posttreatment cephalometric radiograph and cephalometric superimpositions.

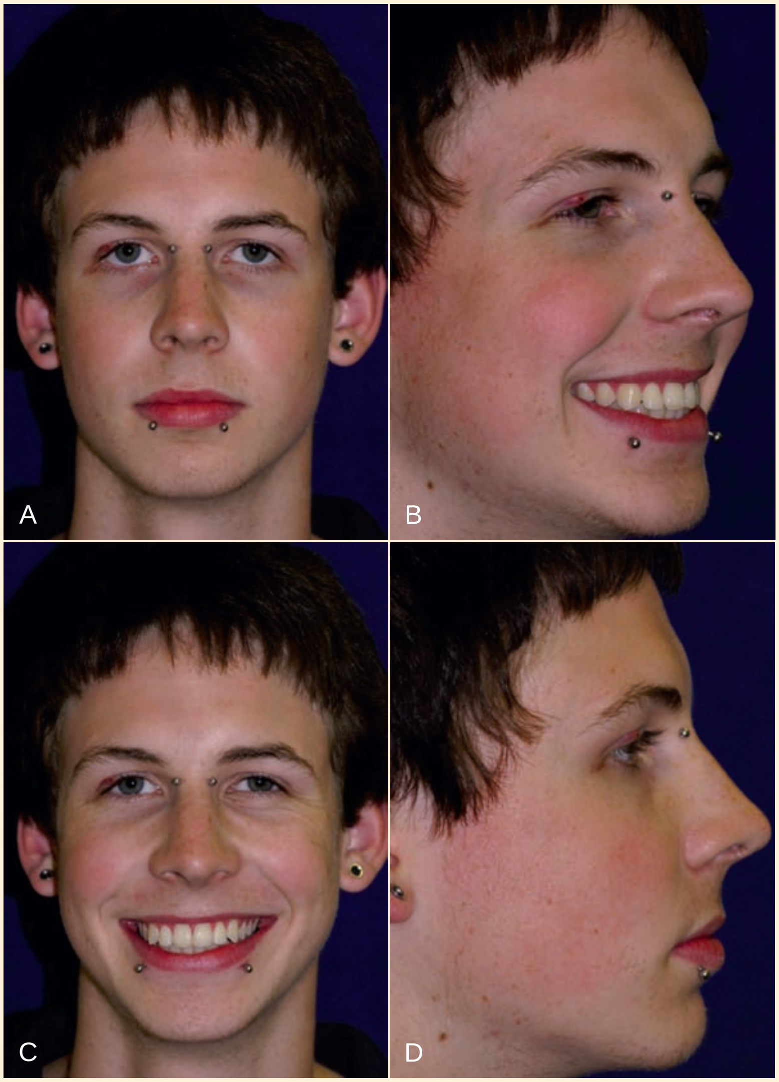

FIGURE 17-28 **A–I,** Records 3 years after the end of active treatment.

Continued

CASE STUDY 17-1 **A SEVERELY CROWDED LOWER ARCH TREATED WITHOUT EXTRACTION—Cont'd**

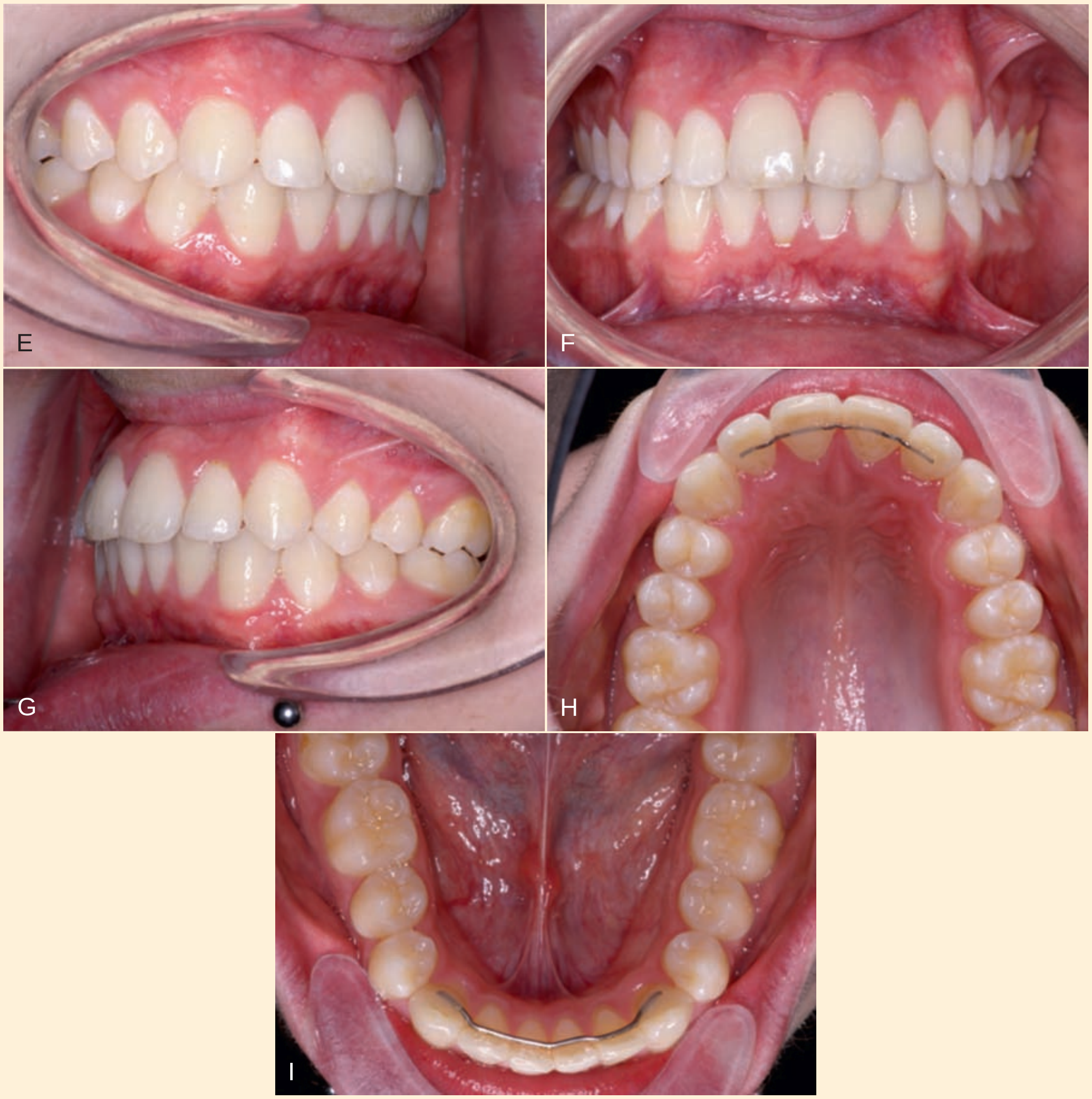

FIGURE 17-28, cont'd

CASE STUDY 17-2

INTERARCH RELATIONSHIP

Dr. Nigel Harradine

Self-ligation in itself does not—in the opinion of this author—reduce the potential role for extractions to reduce an overjet. It may, however, help prevent the creation of an unwanted overjet as illustrated through the cases in Figures 17-20 and 17-21. With regard to establishing a positive overbite, it is equally possible that a reduction in incisor proclination for a given amount of tooth alignment may reduce the need for extractions to maintain a positive overbite, but there will always be cases where any such effect will be insufficient to eliminate the need for extractions. Such a case is illustrated in patient 2 (Figures 17-29 to 17-33), where self-ligation probably facilitated the alignment of very crowded teeth but extractions were still included in order to help achieve the incisor relationship.

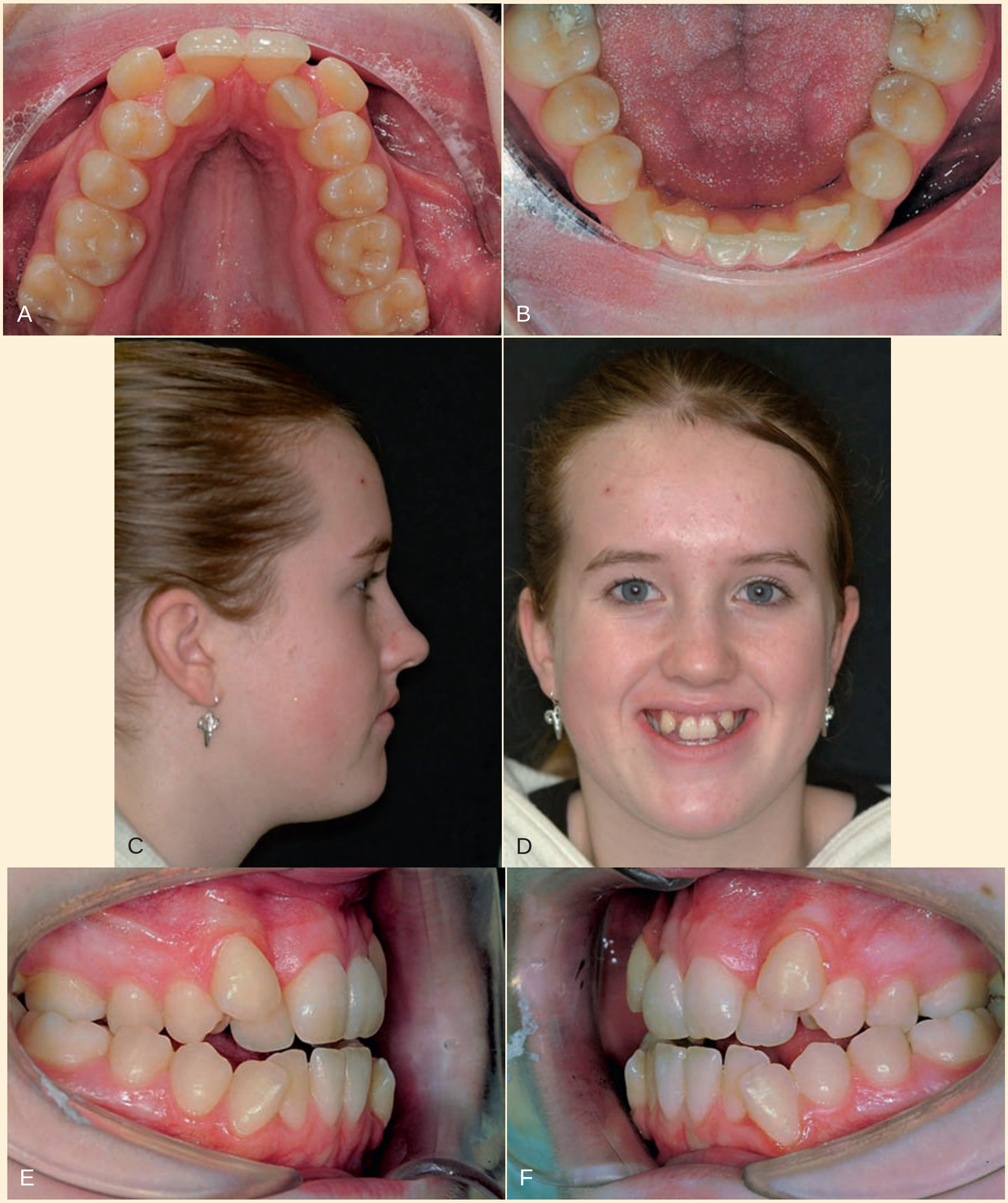

FIGURE 17-29 A–F, Start records of patient 2 (Case Study 17-2). The crowding could have been resolved without extraction (see patient 1, Case Study 17-1), but the Class III incisor relationship and, in particular, the lack of overbite influenced the decision to extract.

Continued

CASE STUDY 17-2

INTERARCH RELATIONSHIP—Cont'd

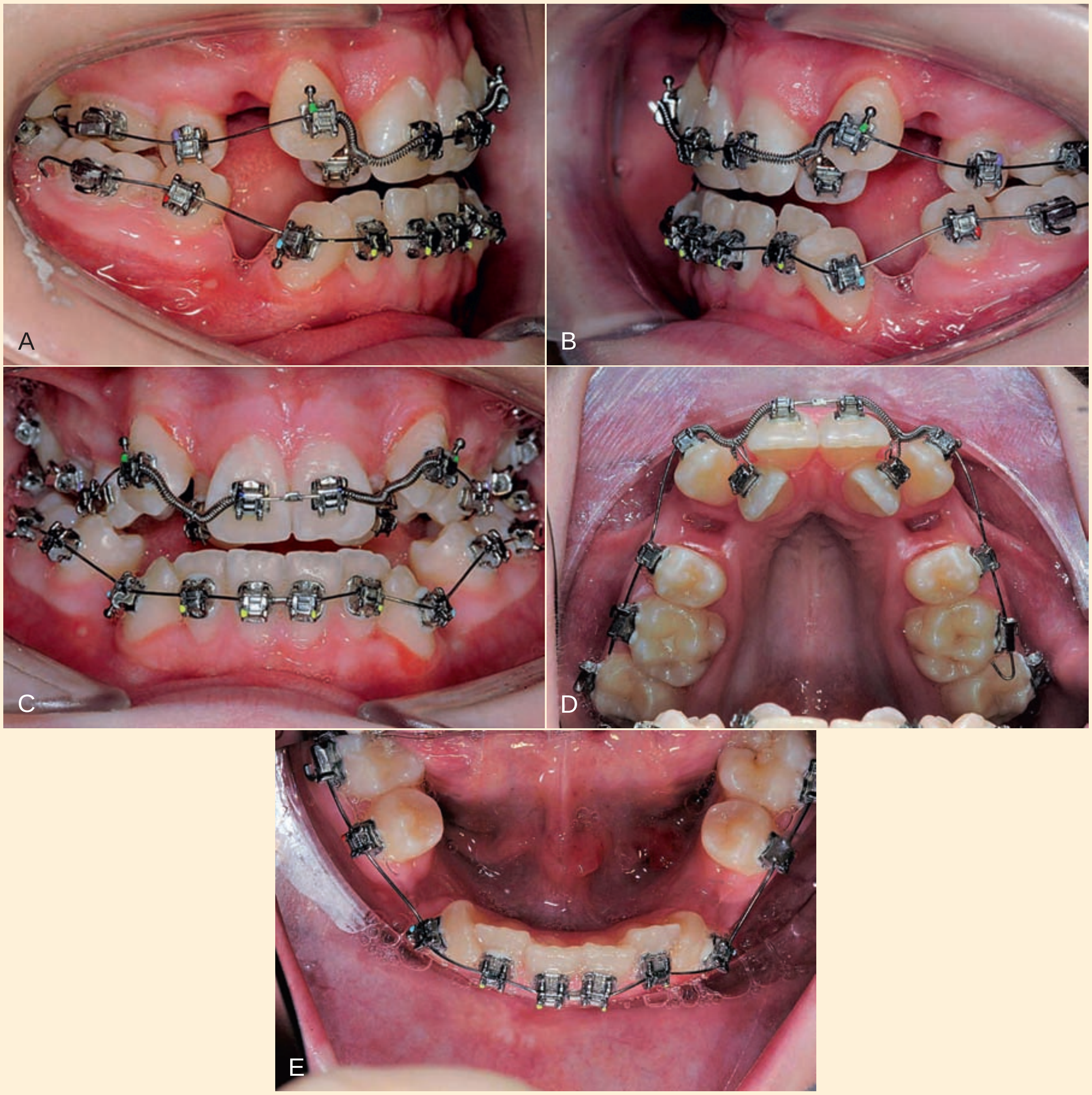

FIGURE 17-30 **A–E,** Patient 2 (Case Study 17-2) with first archwires. Upper (0.013-inch) and lower (0.014-inch) Damon 2 brackets.

CASE STUDY 17-2 INTERARCH RELATIONSHIP—Cont'd

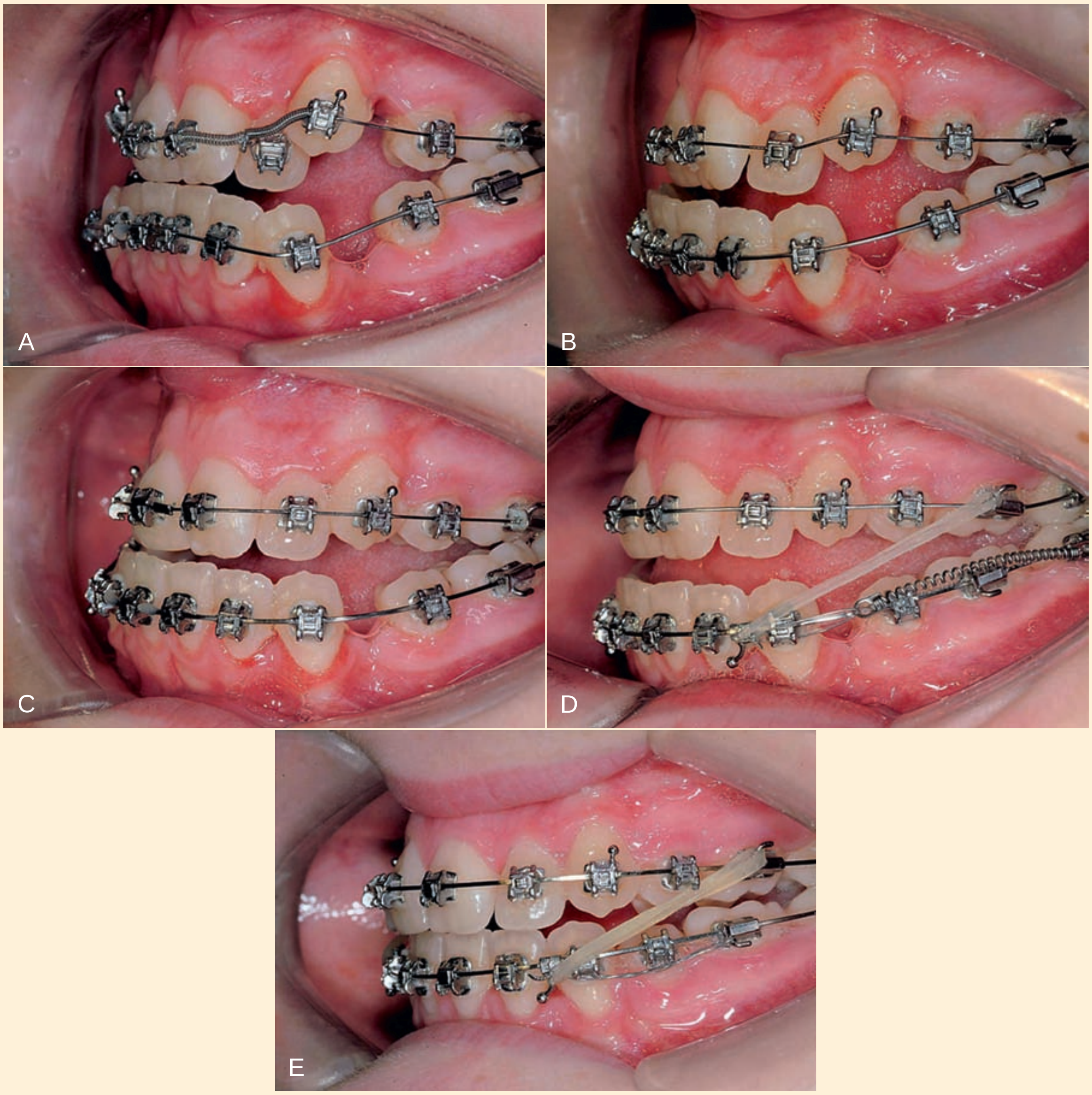

FIGURE 17-31 **A–D,** Sequential visits. **E,** Situation after two further visits. The inclusion of the palatally placed upper lateral incisors from the start has restrained the upper incisor proclination more than the lower despite the greater crowding in the upper arch.

Continued

CASE STUDY 17-2 **INTERARCH RELATIONSHIP—Cont'd**

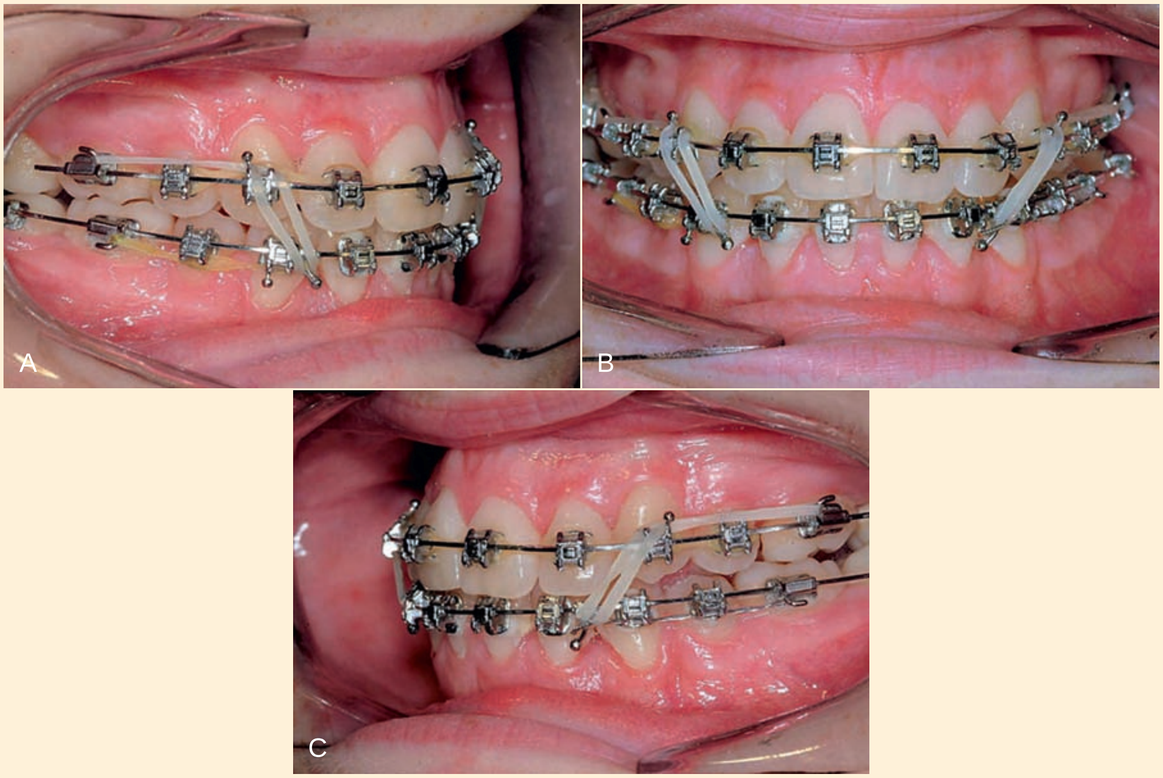

FIGURE 17-32 **A–C,** The 0.019- × 0.025-inch beta titanium wires to detail tooth positions, especially to place buccal root torque on the upper lateral incisors. The selective use of low torque brackets on those two teeth would have reduced or eliminated the need for that torque correction.

CASE STUDY 17-2 **INTERARCH RELATIONSHIP—Cont'd**

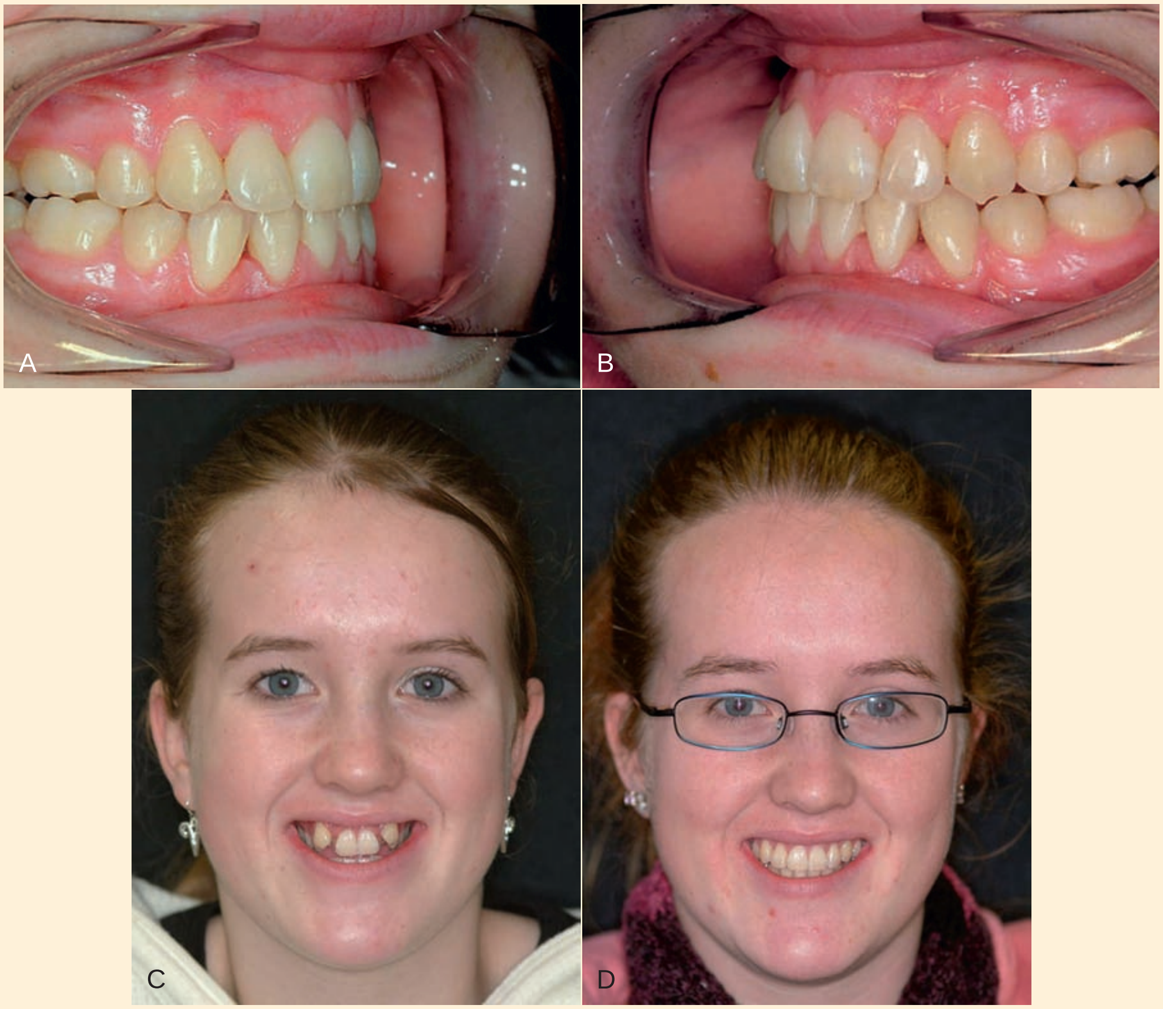

FIGURE 17-33 **A, B,** Occlusal relations at the end of active treatment. **C, D,** Change in smile aesthetics.

Crowding

The combination of low friction and good archwire control that self-ligation provides would be expected to facilitate the alignment of crowded arches without extractions—if that is desired. This biomechanical reason for extraction should therefore be correspondingly reduced. It should, however, be recalled that despite the strong evidence for lower friction and good control, studies to date have not confirmed a generic increase in speed of alignment. The case study of patient 1 treated by Dr. David Birnie demonstrates that severe crowding can be accommodated without extraction if that is the desired goal in a specific instance.

PRACTICAL CONSEQUENCES FOR CLINICAL TECHNIQUE

Choice of Self-Ligating Bracket

A bracket type should be chosen that most closely meets the list of desirable properties for an ideal self-ligating bracket. Particular value should be placed on a bracket that is very easy and comfortable to open and close and yet can reliably engage and retain archwires of the full range of diameter and stiffness. A good view of the degree of engagement of the wire in the slot prior to and during attempted slide or clip closure is a great advantage in preventing excessive and ineffective forces being placed on the teeth during attempted archwire insertion.

Practical Tips in Light of the Evidence

In view of the currently established properties of self-ligation as evidenced by the investigations discussed earlier, it seems logical to recommend the following differences in clinical technique in comparison with conventional ligation.

Because archwire changes are faster and easier,[22] take advantage of this to more routinely remove, check, and replace archwires. This can be useful in checking the remaining activation and any deformation of aligning wires and can facilitate oral hygiene instruction during the appointment.

In view of the much lower friction,[27] be rigorous in placing stops or hooks on the archwire to prevent distal wire pokes. Archwires with preloaded crimpable stops or presoldered hooks are the most efficient method. An upper arch will require two such stops because of the larger anterior interbracket spans and the need to place stops anterior to any crowding to permit distal movement of an aligning wire unhindered by the stop(s).

Because the low friction leaves higher net forces on teeth,[53] aligning wires must be of small diameter to ensure sufficiently low aligning force. In a 0.022-inch slot, initial wires should rarely be larger than 0.014 inch and frequently smaller than that. An important second advantage of thin initial wires is that the greater space between archwire and bracket facilitates the relative movement between bracket and archwire and hence between adjacent teeth that is necessary for teeth to align.

Because it is more possible to fully engage wires in malaligned teeth, the temptation to rapidly progress to thicker wires should be resisted. This would negate the advantages outlined in the point earlier. Lighter wires will—if still active—be more effective at delivering tooth-moving forces than with conventional brackets.[53]

Once teeth are aligned, there is then no advantage in scheduling appointments less frequently than with conventional ligation.

With passive ligation, it is important that intermediate aligning archwires have a bucco-lingual dimension that is as large as the subsequent stainless steel archwire. The full and secure archwire engagement has the corollary that incomplete archwire engagement cannot inadvertently occur and persist as it does with conventional ligation.

In view of the secure archwire engagement, it is possible to be less wary of applying light traction directly to a tooth rather than to a hook on the archwire. Such a tooth will experience very little loss of rotational control.

Anticipate greater benefit from the combination of low friction and good control in cases where individual teeth require sliding along the archwire. This is a particular feature of the treatment of hypodontia cases.

In light of the consideration of possible but as yet unproved qualitative differences in tooth movement, the following change in clinical practice may also seem appropriate.

Irregular teeth may align with relatively less incisor proclination and more buccal segment uprighting or expansion. This may appropriately lead to more therapeutic diagnosis in relation to extractions. If after arch alignment, extractions are judged to be necessary, little time will have been lost because of the properties of self-ligation during alignment. If extractions prove not to be necessary, then this irreversible step will have been avoided.

SUMMARY

Self-ligating brackets are a highly active area of technical development, thought-provoking clinical practice, and research. They have been commercially available for almost 30 years, but only in the past decade has their use spread beyond a minority of enthusiasts. This proliferation of types of self-ligating brackets and the large increase in their clinical use has been sparked partly by very significant advances in bracket design and manufacture. Brackets are now available that are very reliable and very easy to use. Of equal importance has been a rapid growth in the evidence for and appreciation of the combined advantages of secure full ligation, low friction, and speed of archwire ligation and removal. The shortcomings of the previously dominant elastomeric ligation have come to be generally appreciated, and orthodontists who are understandably more skeptical about some of the claims made for self-ligation are nevertheless using these brackets and enjoying the speed of archwire changes, the cleanliness of appliances that lack elastomerics, the effectiveness of light archwires with low friction, and the security of ligation and resulting tooth control. However, beyond these core advantages, much remains to be securely supported by research. The widespread clinical impression that self-ligation enables faster and better treatment has yet to be robustly established. Equally, hypotheses that torquing or finishing performance is deficient with self-ligation also lack good supporting evidence.

The question of a greatly reduced need for extractions is of real interest and is stimulated by some impressive case presentations, but currently lacks hard data. Although consistently faster and easier tooth alignment has not been statistically demonstrated in random clinical trials, some retrospective studies and also first principles concerning low friction and good archwire control would support the clinical impression that this can occur and that the need for extractions purely to provide space for arch alignment may therefore be reduced. Other reasons for extractions may also be weakened, but these hypotheses similarly await further results, particularly from the studies of the forces with self-ligation in relation to forces from the soft tissues. An encouraging trend is the recent development and use of much more sophisticated force measurement systems and more realistic simulations of in vivo effects. An important conclusion that seems to be emerging from such research is the concept that self-ligation does not automatically reduce forces applied to teeth but does enable much lighter applied forces to be effective at moving teeth by substantially altering the ratio between desirably light tooth-moving forces and the unwanted reciprocal forces. In view of the proposal that self-ligation correspondingly alters the ratio of incisor proclination and buccal segment expansion when crowded teeth align, the current research into the periodontal and aesthetic consequences of wider dental arches is a welcome area of investigation. The question of stability of expanded buccal segments is likely to prove hard to establish in the wake of previous studies of long-term incisor stability and the resulting trend with all appliances to recommend indefinite retention. At the least, self-ligation is now a rapid and effective form of ligation. It does not of necessity change a clinicians' treatment goals or mechanics but can fairly be said to facilitate a wider choice in these respects. The next few years will resolve many of the questions discussed in this chapter, but it is beyond doubt that the questions are stimulating and of very significant consequence for the care of our patients.

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CHAPTER 18

Lingual Orthodontics with Completely Customized Appliances

Dirk Wiechmann

OUTLINE

Introduction
  Reduced Risk of Decalcification
  Accurate Realization of an Individual Treatment Plan
  Improved Third-Order Control
Main Differences between Labial and Lingual Techniques
  Anatomical Variations of the Lingual Tooth Surfaces
  First-Order Compensations
  Torque Control
  Exposure of Bonding Area
Development and Manufacture of a Customized Lingual Appliance
  Manufacturing Process
  Basic System and Options
Specific Lingual Mechanics
  Treatment without Extractions
  Treatment with Extractions
Summary

INTRODUCTION

Despite numerous efforts by experienced clinicians and continuous improvements, a lingual technique using conventional appliances has not been fully established.[1–8] The introduction of customized brackets and archwires will be described and illustrated as used in the Incognito System (TOP-Service für Lingualtechnik GmbH, a 3M Company, Bad Essen, Germany). A customized appliance has allowed clinicians to integrate the lingual technique successfully into their everyday practice.[9–13] Because lingual treatment with a customized system not only is more comfortable for the patient but also is practical for the orthodontist, it has become by far the most widely used lingual appliance since its introduction in 2004 (Figure 18-1).

Although lingual appliances are the most aesthetic alternative for correcting malocclusions, other far more important reasons for using completely customized lingual appliances have emerged compared with alternative treatments.

Reduced Risk of Decalcification

The percentage of patients in whom decalcification occurred during orthodontic treatment is reported to range from 13% to 75%.[14–17] Because full remineralization cannot be assumed, every orthodontist should endeavor to keep decalcification, which can be caused by fixed orthodontic appliances, to an absolute minimum. As demonstrated by recent prospective randomized trials, the risk of decalcification in the area around the bracket is nearly five times lower when using completely customized lingual appliances.[18] Even in the rare case where decalcification is found, it does not have any major aesthetic consequences due to the lingual location. These issues should be discussed during the first consultation and not exclusively with those patients considered high risk.

Accurate Realization of an Individual Treatment Plan

When completely customized lingual appliances are manufactured, a treatment goal is defined for each patient with the help of a target setup.[9,12] This is especially helpful for complex treatments, because the orthodontist is able to gather an exact idea of the quality of the potential outcome. Thalheim and Schwestka-Polly[19] report that the treatment target can be put into practice relatively accurately. For instance and with reference to the intercanine distance, a mean deviation of less than 0.5 mm from the setup to the actual outcome shows that the individual treatment goal was clinically achieved with high accuracy.

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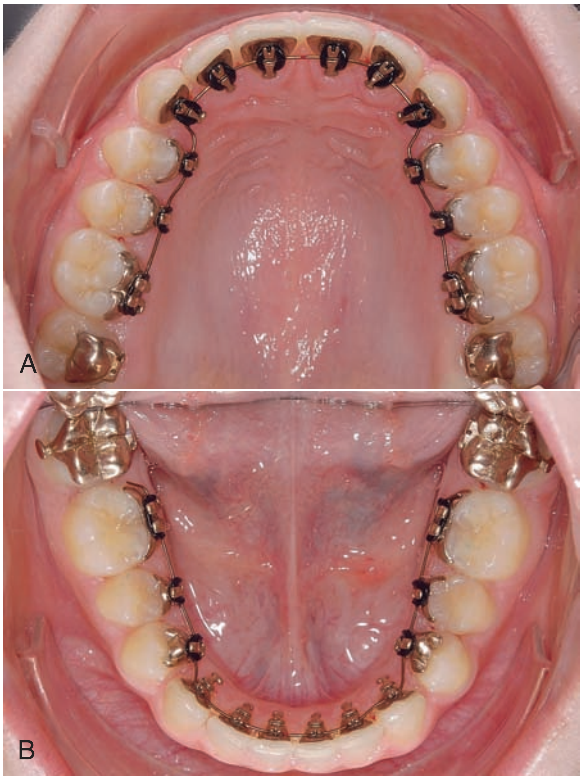

FIGURE 18-1 **A, B,** A completely customized lingual appliance: Incognito. Situation following indirect bonding and insertion of thin superelastic NiTi archwires. The bracket bases are extended over the occlusal surface of the second molars and the first lower premolars. In the lower anterior area, the archwire is placed in the self-ligating slots.

Improved Third-Order Control

The requirement of an improved third-order control, obtained with slot-filling archwires inserted in precision slots, gives the orthodontist the opportunity to realize tooth movements that can be achieved only with some difficulty if labial appliances are used. This situation becomes particularly apparent in the area of the lower anterior segment. For example, in a pilot study on controlling the position of the lower incisors in a combined Incognito and Herbst treatment, Wiechmann et al.[20] reported that the setup prescription could be accurately achieved. Not only can undesired proclination be avoided, which has been often described with labial appliances,[21,22] but in half of the cases there is even a remarkable uprighting effect as determined by the setup.[13,20] Using the customized lingual appliance, this three-dimensional control is achieved due to the minimum torque play by the slot-filling archwires in their precision-made slots.[23]

A substantially lower risk of decalcification, the accurate achievement of the individual treatment objective, and excellent three-dimensional control are the main reasons, along with the aesthetic advantages, that have attracted orthodontists to use the customized lingual appliance. This chapter will review new developments and the specific characteristics to be considered when using a new generation of lingual appliances with special reference to the customized incognito system.

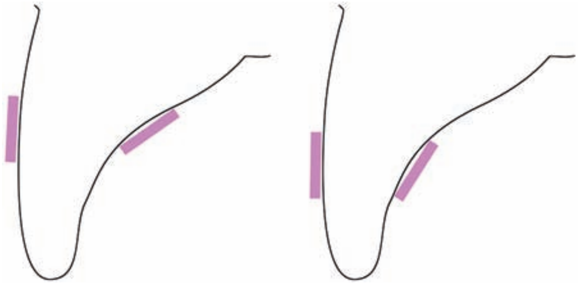

FIGURE 18-2 A slightly different positioning height of the bracket has only a small impact on torque (2 degrees) with a labial appliance. On the lingual aspect, the same height difference results in a major torque difference (22 degrees).

MAIN DIFFERENCES BETWEEN LABIAL AND LINGUAL TECHNIQUES

Anatomic Variations of the Lingual Tooth Surfaces

The labial and lingual differences in tooth morphology are substantial. Morphologic variability of the lingual surfaces of teeth results in a wide range of individual variation compared with the labial surface. For instance, the labial surface of an upper central incisor always follows a similar pattern, while its lingual surface shows marked morphologic variations between individual teeth. Therefore, designing the treatment appliance based on mean values, as with labial techniques, is impossible. Moreover, even a small height deviation in the position of the brackets results in a substantial effect on the third-order prescription (Figure 18-2). As a consequence, the application of the intended torque values can only be achieved with an approach combining completely customized bracket bases with indirect bonding. This provides the orthodontist with reproducible high-quality outcomes from customized lingual appliances placed with an indirect bonding protocol. Without an understanding of the history of lingual appliances, just copying the approach of conventional, labial techniques led to disillusionment with lingual appliances in the 1980s—especially in the United States.

First-Order Compensations

Looking at an ideal dental arch from the occlusal view, the labial surfaces of the teeth can be found along a more or less regular arch line. On the lingual side, on the other hand, the teeth exhibit a pattern where surfaces are irregular. The thickness differences occurring between individual teeth have to be compensated in some way. This, too, is achieved with a laboratory process. There are three main strategies to compensate these irregularities (Figure 18-3):

1. *Compensation with first-order customized archwires that level out the tooth thickness differences* (Figure 18-3, *A*): The customization of the brackets only serves the programming of the second-order and third-order dimensions, which allows for a comparatively flat profile.[9,10,12]
2. *Compensation by way of more extensive adjustments and additions to the brackets in the course of customization:* Brackets are set up not only with second-order and third-order programming but also with first-order programming.[7] This results in a considerable increase in the appliance thickness, which may be extreme in some cases and lead to patient discomfort. Because the brackets incorporate the three-dimensional programming in its entirety, "straight wires" may be used (Figure 18-3, *B*). Although the use of straight wire appliances has been established in labial techniques, it results in considerable disadvantages in the lingual technique for both the patient and the orthodontist because of the markedly thicker brackets.

Hohoff et al.[24] and Stamm et al.[25] report that thicker appliances cause more patient discomfort and more problems with speaking and eating. Tongue irritation is also observed more frequently.

The short interbracket distance becomes even shorter because of the increased bracket thickness. This not only makes inserting the archwires more challenging, but also makes complete bonding of all brackets impossible at the start of treatment, even in moderate cases of crowding, because the brackets are too bulky (compare with Figure 18-14).

The more bulky the bracket (i.e., the longer the lever arms), the higher is the rate of bracket loss, because there is statistically more chance of biting and debonding a thicker bracket.

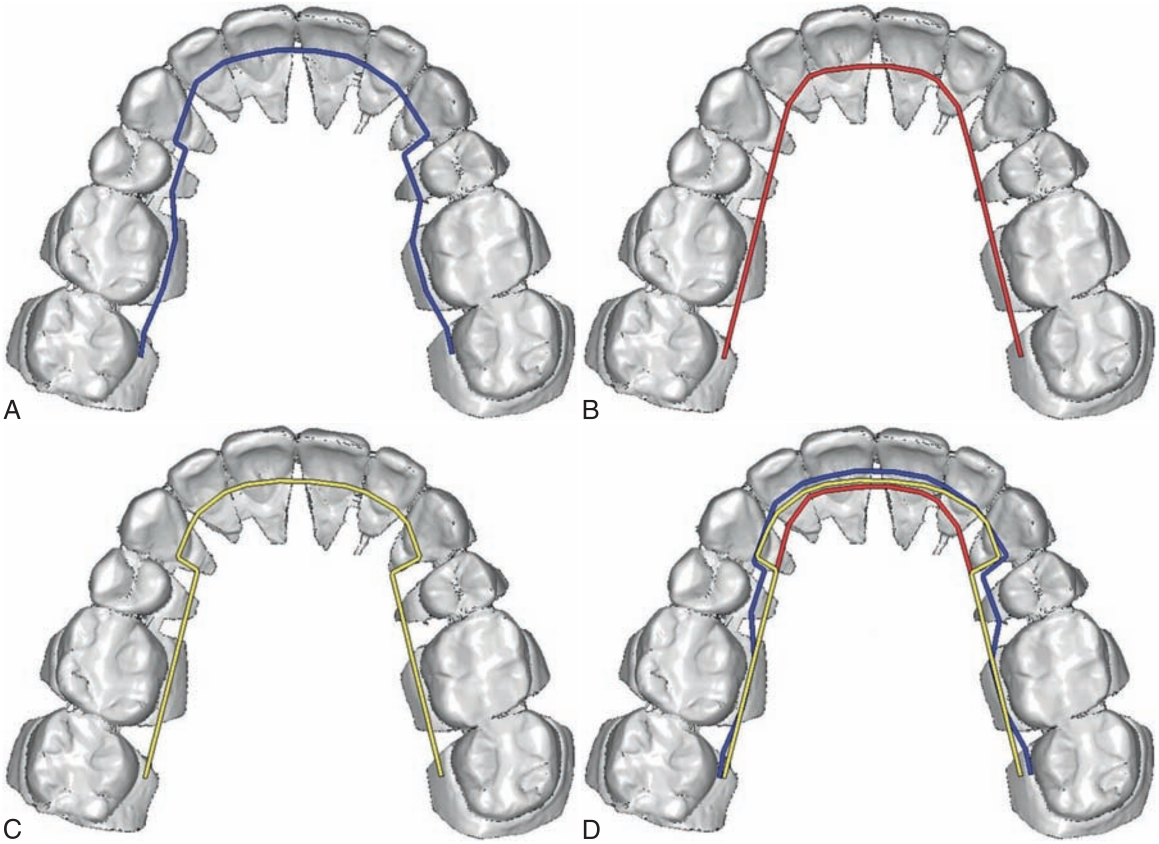

FIGURE 18-3 **A,** Different tooth thicknesses are compensated by first-order archwire bends. **B,** The archwire is straight. Compensation of the different tooth thicknesses must be accomplished by thicker brackets; therefore, additional composite is required under the brackets in the laboratory process. **C,** Mushroom arch form. Two first-order bends are placed between the canines and premolars. **D,** Superposition of the three types of archwire. In the anterior segment, major differences can be noticed. The archwire, which is completely individual in the first-order (*blue*), allows for the flattest appliance. The straight archwire (*red*) produces by far the biggest restriction for the tongue.

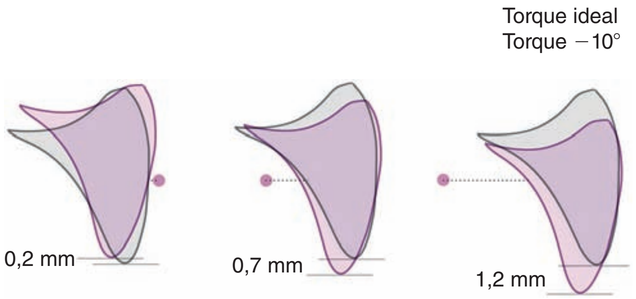

FIGURE 18-4 Effect of incorrect torque (–10 degrees) on the vertical position of the incisor edge of an upper central incisor. **A,** With a labial appliance, only 0.2-mm vertical discrepancy can be noticed. **B,** The same incorrect torque creates an increased vertical discrepancy (0.7 mm) even if a very flat lingual appliance is used. **C,** Thicker lingual appliances (e.g., lingual straight wire appliances) are not only much more uncomfortable for the patient; they are also much more prone to third-order problems.

The longer the distance between tooth and archwire, the more challenging it is to correct torque problems in the third dimension (Figure 18-4).

3. *Partial first-order compensation by the archwires:* in this case, only the difference in thickness between the canine and the first premolar is compensated with a first-order bend of the archwire. Accordingly, the archwire is straight running from canine to canine and from premolar to second molar. The shape of this archwire setup reminds one of a mushroom, which is why the lingual technique was also called the "mushroom technique" by its pioneers[3] (Figure 18-3, *C*).

Torque Control

The major differences between labial and lingual appliances with regard to treatment mechanics are the importance of accurate torque control and the consequences that this has on the appliance. Incorrect torque results in a completely different effect in a labial bracket than in a lingual appliance as illustrated in Figure 18-4. Two upper central incisors are depicted, one of which exhibits an ideal position, while the other presents a torque problem of –10 degrees. When a labial appliance is used, this malposition will go unnoticed by the patient and only an astute orthodontist will recognize the problem (Figure 18-4, *A*). When a lingual appliance is used, an incorrect torque directly causes a visible malposition in the vertical plane and the tooth appears extruded (Figure 18-4, *B*). As the distance between the tooth surface and the archwire increases, which is the standard situation when using a lingual straight-wire approach, the greater is the malposition (Figure 18-4, *C*), which will not go unnoticed by the patient. These aspects illustrate why more accurate torque control is needed when lingual appliances are used.

In state-of-the-art orthodontic appliances, torque control is achieved by the exact fit of a rectangular archwire into the bracket slot. To ensure perfect third-order control, either full engagement of the slot by the archwires or smaller archwires with overcorrections have to be used. Acceptable torque control in the course of the lingual treatment can be realized only if archwires and slots are precisely manufactured with only minimal tolerances.[26] The main cause for marked torque play in labial appliances, in particular in their "passive self-ligating systems," is their design with considerably oversized bracket slots.[27] Oversize of more than 15% on average of the nominal size may occur in these labial appliances. As an example, the slot in a 0.022-inch bracket system may have a real slot size of 0.025 inch. Nonetheless, reproducible, good outcomes can be obtained with these types of labial systems, but there are differences between labial and lingual techniques. Consequently, the requirements for lingual appliances continue to be different.

Exposure of Bonding Area

Most orthodontic patients are children and adolescents. Within this age group, the bonding area of the lingual surface can be reduced, especially with teeth that have just erupted. This is true, particularly for the upper and lower second molars and the lower premolars. Bonding conventional lingual appliances is therefore difficult or impossible. This is the main reason why lingual treatment has been provided only to adults in the past who are also more self-conscious about the appearance of labial appliances. The number of adults requesting orthodontic treatment has always been relatively low, so conventional lingual appliances were only appropriate for a limited group of patients. The use of the completely customized lingual appliances, where bonding pads can be individually designed, and in cases of a reduced bonding area, partially extended over the occlusal surface, now opens up a new target group including both children and adolescents (see Figures 18-19 and 18-20).

DEVELOPMENT AND MANUFACTURE OF A CUSTOMIZED LINGUAL APPLIANCE

The idea to develop a completely customized lingual appliance is a straightforward response to the problems both the orthodontist and the patient are faced with when a conventional lingual appliance is used for treatment. These problems are also the main reasons why up to this point lingual techniques have not been used on a large scale. The main problems were:

- Issues of patient discomfort
- High rates of bracket loss and difficulty of rebonding
- Difficult and partially unmanageable finishing

The development of the Incognito System was based primarily on these issues. At the same time, the solutions to these problems resulted in unique features and will be described in detail. The improvement of patient comfort is achieved by a combination of extremely flat brackets together with archwires completely customized in the first order.[24,25] The customized bracket bases, which allow for a considerably larger bonding surface than with conventional lingual brackets, increase the bond strength, thereby reducing the debonding rate. Furthermore, rebonding a debonded bracket is possible without problems thanks to the definite fit of the large, customized bases. The most critical task of the finishing process is third-order control. The Incognito System acknowledges the challenge of torque control and resolves it with a combination of full-size finishing archwires inserted in precise slots.[23]

These unique features have solved the three main problems encountered when using conventional lingual systems. This is why the Incognito System became the most widely accepted lingual appliance soon after it was introduced at the end of 2004.

Manufacturing Process

The first step of the manufacturing process starts with obtaining impressions for the appliance. A two-phase silicone impression allows for good reproducibly, which is a *conditio sine qua non* when manufacturing a completely customized lingual appliance. A patient-individual setup is then produced in the dental laboratory, based on the information provided by the orthodontist; this setup can then be cross-checked by the orthodontist prior to the start of manufacture. The setup is scanned using an optical scanner (Figure 18-5). The minimum resolution of the scanner is 20 microns. The next step is designing the customized brackets digitally using purpose-developed software.

After the slot plane has been defined, the extent of the customized bracket base is determined (Figure 18-6). The extraordinarily large bonding surfaces ensure high bond strengths, and therefore the rate of bracket loss is low. In addition, they allow direct rebonding, because the precise fit of the bracket base onto the tooth surface locks it into the desired position. Subsequently, the body of the bracket is fused to the bracket bases while remaining in the previously defined slot plane (Figure 18-7). The goal is to locate the slots as closely as possible to the tooth surface. All functional items, such as hooks and wings, can be individually adapted with the software. This results in an extremely flat appliance, which consequently is comfortable for the patient. Ease of wearing the system does not compromise its functionality, because functional items are individually customized rather than eliminated. The brackets are then converted into an actual analogue using rapid prototyping machines. Only procedures that deliver extremely precise slots and therefore fulfill the advanced requirements are selected. The brackets are prepared for casting and then cast using an alloy with a high gold content. This is the only way to ensure reproducible accuracy of slot sizes in the casting procedure. After final polishing, all slots are measured manually to ensure the correct size as a means of

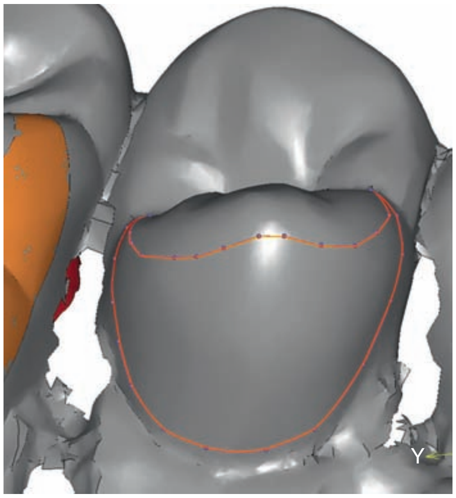

FIGURE 18-6 Designing of the customized bracket base.

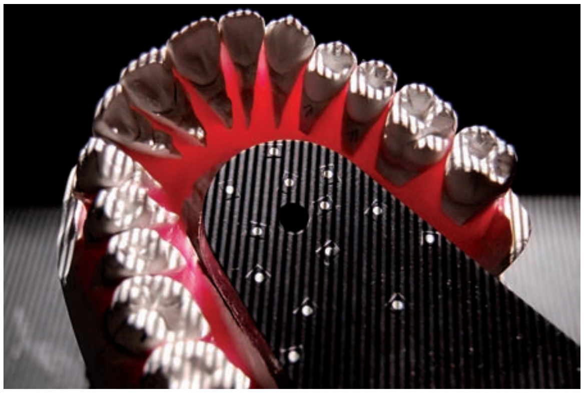

FIGURE 18-5 Scanning of the individual setup model with an optical scanner using monochromatical light.

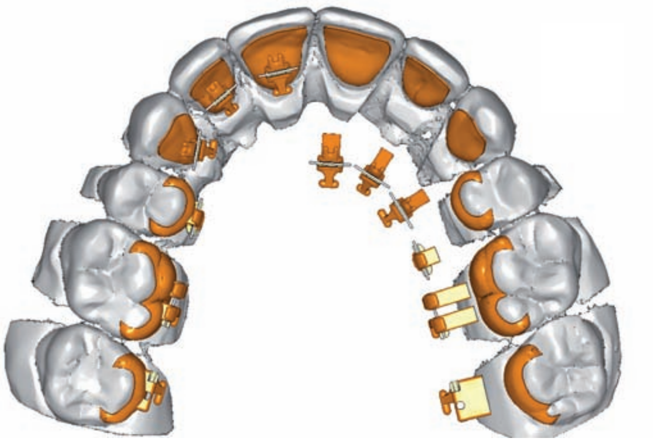

FIGURE 18-7 Positioning of the bracket bodies. Functional elements like hooks and wings can be individually adapted.

quality control. The preset tolerances for the 0.018-inch slot used are 0.0180 inch minimum and 0.0183 inch maximum (Figure 18-8).

The next step is to line the bracket bases with a thin composite film and to position them onto the malocclusion model (Figure 18-9). Then the transfer tray is made using a two-phase silicone or a transparent thermoplastic material (Figure 18-10). With the help of this bonding tray, the Incognito appliance is placed intraorally in one simple procedure using an indirect bonding protocol.

The customized archwires are manufactured by CAD-controlled bending robots (Figure 18-11). The Pro-Bending software ensures accurate calculation of the archwire design based on the STL (standard triangulation language) data obtained in the positioning process. The archwires are customized in the first order (Figure 18-12). Second-order and third-order information is contained in the brackets. In some archwires, extra torque in the area of the maxillary anterior teeth is incorporated. If space has to be opened up or closed with the help of sliding mechanics, the archwires used during this period of treatment are straight in the lateral segments. If needed, first-order, second-order, and third-order bends can be incorporated into the final archwires by the bending robot during the finishing process.

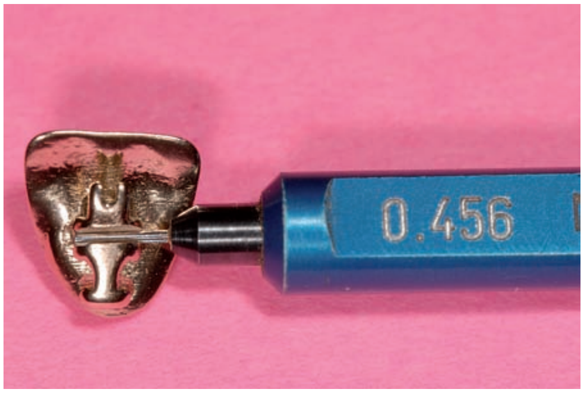

FIGURE 18-8 Quality control of the slot size. Tolerances are from 0.0180 to 0.0183 inch.

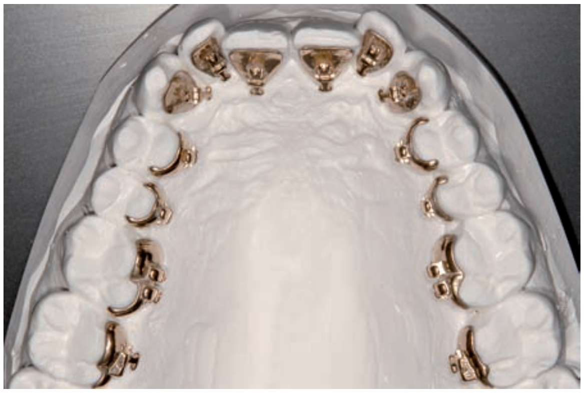

FIGURE 18-9 Positioning of brackets onto the malocclusion model.

FIGURE 18-11 The archwire bending process using robots.

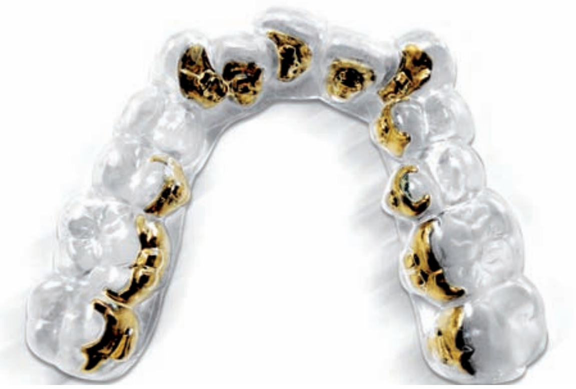

FIGURE 18-10 Transparent bonding tray with customized brackets for indirect bonding.

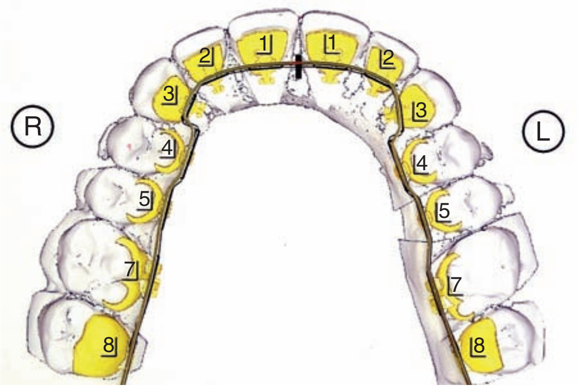

FIGURE 18-12 Archwire template with customized 0.016- × 0.022-inch superelastic NiTi.

Basic System and Options

The Incognito System uses ribbonwise archwires with vertical insertion in the anterior segment and horizontal insertion in the lateral segments (Figure 18-13). After extensive clinical testing including all other possible variants and combinations (edgewise versus ribbonwise, vertical versus horizontal slot), the design described earlier has established itself as an important advance in lingual appliances. All brackets have a hook, which can optionally be left off the molar tube. The brackets feature an accessory self-ligating slot in the area of the mandibular anterior teeth (see Figure 18-1, *B*).

One option that is selected most often is the so-called occlusal pad (see Figures 18-1, *A, B*). This is a bracket base for bonding that extends over part of the occlusal surface. Orthodontists often choose this option when the lingual tooth surface is small or when an additional bite plane in the area of the second molars is indicated for bite opening. An upper canine bracket can also be manufactured, as an option, with a bite plane. If required on certain teeth, such as upper first molars, bands can be requested rather than brackets. They can be used in combination with various auxiliaries, such as headgear tubes, Herbst rods, and tubes for removable transpalatal bars (see Figure 18-20, *J, Q*). In the case of an impacted canine, a bracket for the unerupted tooth can be designed digitally by mirroring the contralateral canine. No additional laboratory process, such as taking an impression after exposing the canine, is needed. For reinforcement of anchorage, a continuous bonding base that will extend over several teeth can be made. In such cases, the archwires in this segment are passive.

The Incognito System is continuously being improved and modified in response to clinicians' suggestions and preferences.

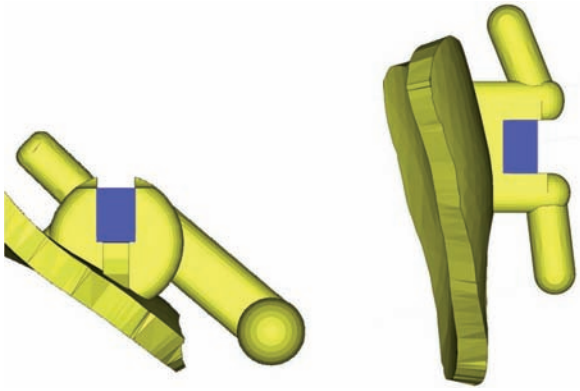

FIGURE 18-13 The Incognito System uses ribbonwise archwires. In the anterior segment, the slot insertion is vertical; in the lateral segments, the slot insertion is horizontal.

SPECIFIC LINGUAL MECHANICS

Treatment without Extractions

In cases without extractions, bite opening and leveling of the curve of Spee, space creation, and Class II correction are the most frequent treatment needs. Bite opening is achieved by the mere insertion of the lingual appliance, because the lower anterior teeth will bite on the appliance in the upper frontal region (see Figure 18-19, *S*). Leveling is achieved by the ribbonwise orientation of the archwires of the Incognito System, which has advantages over the edgewise-oriented appliances (see Figure 18-13). Therefore, the lateral open bite that is a consequence of initial bite opening at the start of treatment resolves with leveling of the occlusion. The accessory self-ligating slot in the mandibular arch is helpful in correcting lower anterior crowding. Even in more crowded situations, the first archwire can simply be inserted into the vertical self-ligating slots (Figure 18-14). Handling the clip mechanism is easy and does not need an additional ligature or pliers.

As opposed to conventional lingual bracket systems, the use of completely customized lingual appliances frequently allows initial bonding of all brackets to the teeth even in cases of severe crowding (see Figure 18-14). When the crowded condition is too severe (i.e., the lingual tooth surface is completely excluded) the bracket can only be placed after space has been created. In these cases, the use of compressed, superelastic NiTi archwires has been shown to be clinically effective (Figure 18-15). Crimpable stops are placed bilaterally in the area mesial to the premolars. The archwire template should be used for reference, to achieve accurate placement (see Figure 18-12). When the archwire is inserted, its anterior portion is being compressed, thereby acting as an active

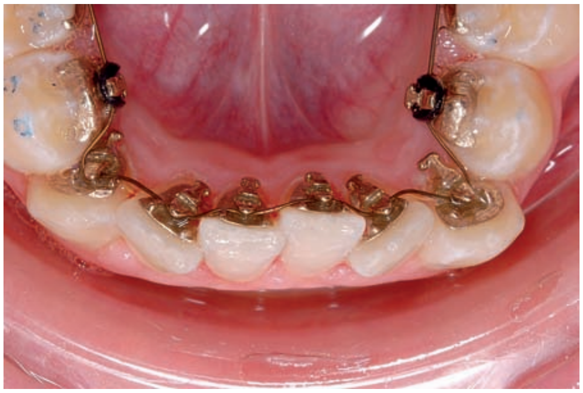

FIGURE 18-14 All brackets can be bonded right from the beginning, despite crowding. A 0.014-inch superelastic NiTi archwire is inserted into the self-ligating slot for initial aligning. Note the extended bracket bases on the first premolars.

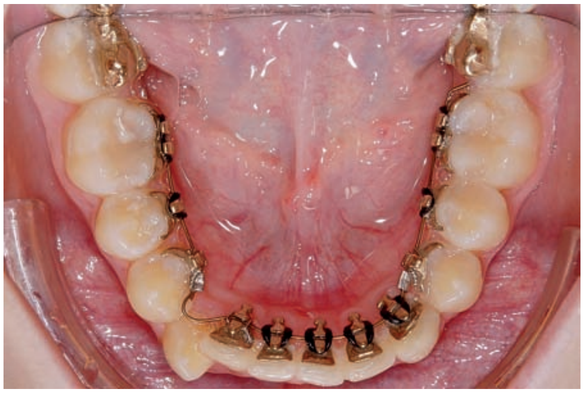

FIGURE 18-15 Crimpable stops are placed mesial to the first premolars with the help of the archwire template. The round 0.014-inch superelastic NiTi archwire compresses in the anterior segment. This will create the necessary space for the lower right canine.

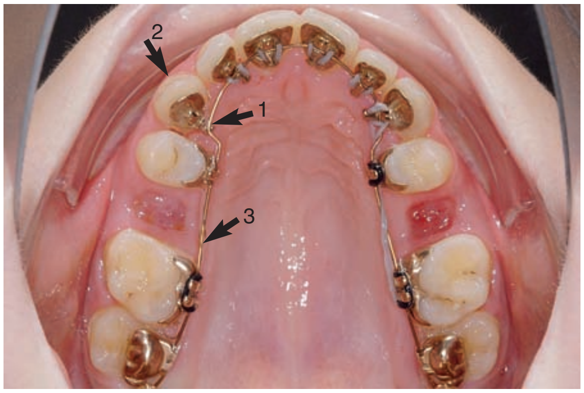

FIGURE 18-16 The upper right canine has to be distalized and rotated distally. A transparent power chain (chicane) is used starting from the hook of the canine going mesially to the buccal side, then back to the lingual side between canine and premolar, and is finally attached to the archwire distal to the second molar tube. The chicane will distalize and derotate the canine at the same time.

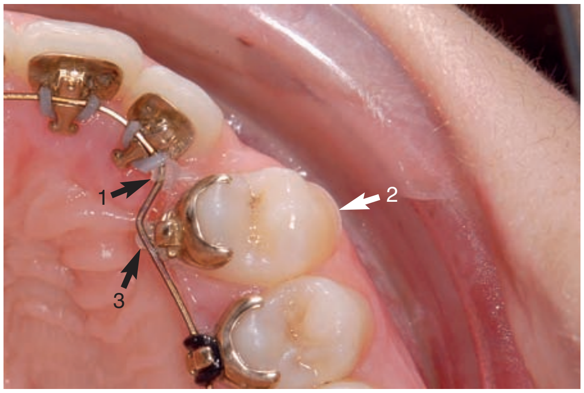

FIGURE 18-17 A transparent power chain (lasso elastic) is used to derotate the premolar. The lasso elastic is attached to the archwire mesial to the premolar and goes to the buccal side. It then goes back to the lingual side distal to the premolar and is attached to the hook of the attachment.

component for space creation. Later, when sufficient space has been gained, the missing bracket can be added in a direct bonding approach. In most cases, the accessory self-ligating slot is then used for further aligning. If interproximal enamel reduction is part of the treatment plan, this should never be done before the initial impression taking stage, because undesirable tooth movement may occur before the day of bonding. Moreover, the risk of inaccurate reshaping is reduced when stripping is carried out during the course of treatment. From the very start, the customized archwires are matched to the treatment plan including any interproximal enamel reduction and do not need any subsequent adaptation.

To correct the Class II relationship, the same mechanics as in labial appliances can be relied on when the Incognito System is used. Yet because of the differences between labial and lingual approaches as described previously, controlling the torque of the upper front teeth is of particular importance. Subsequent to the leveling and aligning phase of the treatment, in which first round and then rectangular NiTi archwires are used, the phase of Class II correction proceeds with rigid stainless steel archwires. The recommended stainless steel archwires are not slot-filling (0.016- × 0.024-inch stainless steel archwire in the 0.018-inch slot). To enable full third-order control, the rigid archwires incorporate extra torque in the upper anterior region (torque play–neutralizing bend) in this phase of the treatment. This torque is incorporated into the archwire at the very moment of fabrication by the bending robot. This is how reliable torque control of the upper front teeth can be guaranteed without further clinical input from the orthodontist.

Furthermore, accurate control of the lower anterior teeth, to prevent proclination, may be desired when flexible or rigid bite jumpers (Forsus or Herbst appliance) are used.[22,28] The use of a full-size stainless steel archwire (0.018 × 0.025 inch) enhances this control so that the treatment requirements can be met. If requested in the treatment plan, even uprighting of the lower anterior teeth is possible, which is a difficult tooth movement to achieve with labial techniques.[20,22,28]

Treatment with Extractions

In cases with extractions, anterior crowding is corrected using superelastic NiTi archwires. The canines first have to be partially retracted. When canines are mesially rotated, a chicane is used. With this transparent power chain, the canine is distalized and derotated in one process (Figure 18-16). To derotate teeth in the anterior area, lasso ties are used on teeth where the archwire cannot yet be ligated (Figure 18-17).

When frontal alignment has been completed, the treatment phase of en masse retraction follows. The 0.016- × 0.024-inch stainless steel archwire used in this phase is straight in the lateral segment, just as with the previous NiTi archwires. This allows space closure along the archwire with sliding mechanics. Torque control in the anterior segment is achieved with extra torque that neutralizes the torque play of the undersized archwire. Where substantial space closure is needed, such as after the extraction of a first molar, double cable mechanics have proven to minimize side effects such as bowing in the lateral segment (see Figure 18-18, *K*). As with labial treatments, mini-screws and micro-screws may be used for anchorage. Although direct mechanics are used in most cases in the maxilla, a rigid indirect anchorage is preferred in the mandible (see Figure 18-18, *K*, *R*). Just as in cases without extractions, managing the closure is also possible with intermaxillary elastics and flexible or rigid bite jumpers.[22,28]

When the space has been completely closed, finishing archwires made of beta-titanium are inserted. In contrast to the previously used NiTi and stainless steel archwires, they are not straight in the lateral segment but have first-order bends incorporated, which is why they improve the occlusion and minimize finishing.

CASE STUDY 18-1

LINGUAL TREATMENT OF ADULT PATIENTS

Adult Extraction Case with Mini-screw Anchorage

Dirk Wiechmann

A 25-year-old patient presents with a Class II Division 2 malocclusion with anterior crowding in both arches. The lower right first molar has to be extracted because of an endodontic problem. The lower right third molar is impacted (Figure 18-18, *A–I*).

In the first phase, canines are partially retracted on a 0.016- × 0.022-inch superelastic NiTi archwire with power chains. These archwires are straight in the lateral segments. The left canine is mesiorotated, so a chicane would be a better choice for retraction (Figure 18-18, *J*). In the second phase, spaces are closed by en masse retraction (Figure 18-18, *K*). Because of the higher anchorage needs on the left side, two mini-screws have been used. A "double cable mechanic" is used to close the space. This mechanic reduces the risk of overloading one screw and helps to prevent side effects, such as a transverse bowing. The 0.016- × 0.024-inch stainless steel archwire is straight in the lateral segments and has an extra torque in the anterior region to compensate for torque play of the undersized archwire. In the third phase, a full-size beta-titanium archwire is used for final detailing (Figure 18-18, *L*). The archwire is individual in the lateral segments. The final result and the treatment plan look similar (Figure 18-18, *L, M*).

In the mandible, rigid indirect anchorage is used to mesialize the second right molar (Figure 18-18, *N, R*). After space closure, the third right molar erupts spontaneously. A customized band is inserted and alignment proceeds with a superelastic NiTi archwire (Figure 18-18, *O, S*). For finishing, a 0.017- × 0.025-inch beta-titanium archwire is used (Figure 18-18, *P*). This archwire is individual in the lateral segments and helps to improve the lateral occlusion without the need for further archwire bending by the orthodontist. The final result and the treatment plan look similar (Figure 18-18, *P, Q*).

Final results after 30 months of treatment are shown in Figure 18-18, *T–BB*. The extraction space in the lower arch was 13 mm, and unilateral space closure took 18 months. The upper incisor torque could be improved despite the correction of the Class II with en masse retraction. The lateral head film and the orthopantogram show parallel roots in the extraction sites and a favorable position of the lower right third molar (see Figure 18-18, *V, BB*). Composite restorations are planned for the upper central incisors. Because the final arch form and the treatment plan are identical, the patient has a full smile despite being an extraction case.

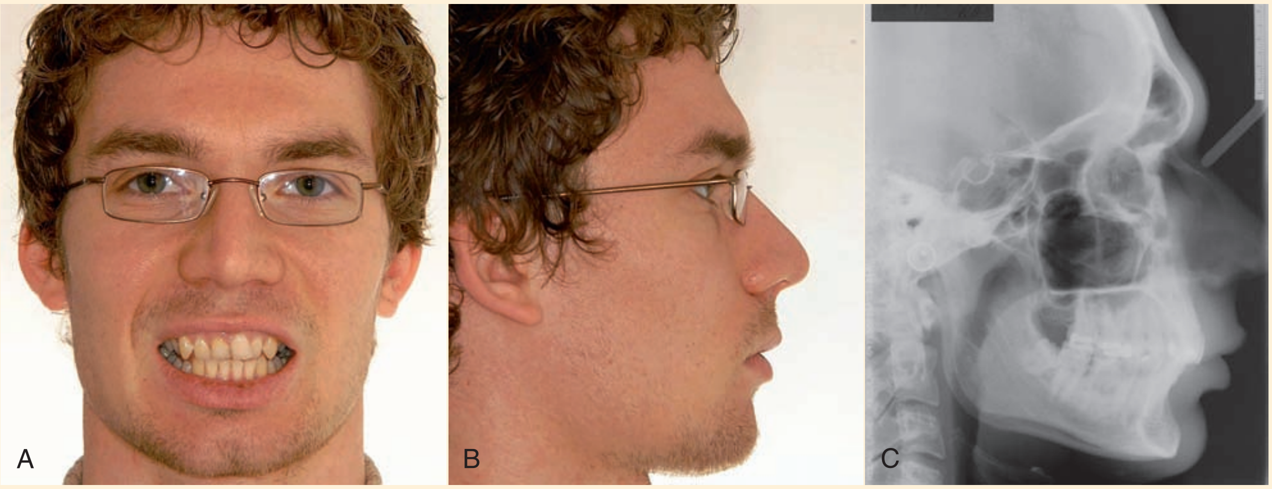

FIGURE 18-18 **A–H,** Extraction treatment of a 24-year-old patient with a Class II Division II incisor relationship complicated by crowding. The lower incisors are proclined. The patient refused a surgical correction of the skeletal discrepancy. Two upper premolars will be extracted for a dentoalveolar compensation of the Class II relationship. The lower right first molar requires extraction for endodontic reasons.

Continued

CASE STUDY 18-1 **LINGUAL TREATMENT OF ADULT PATIENTS—cont'd**

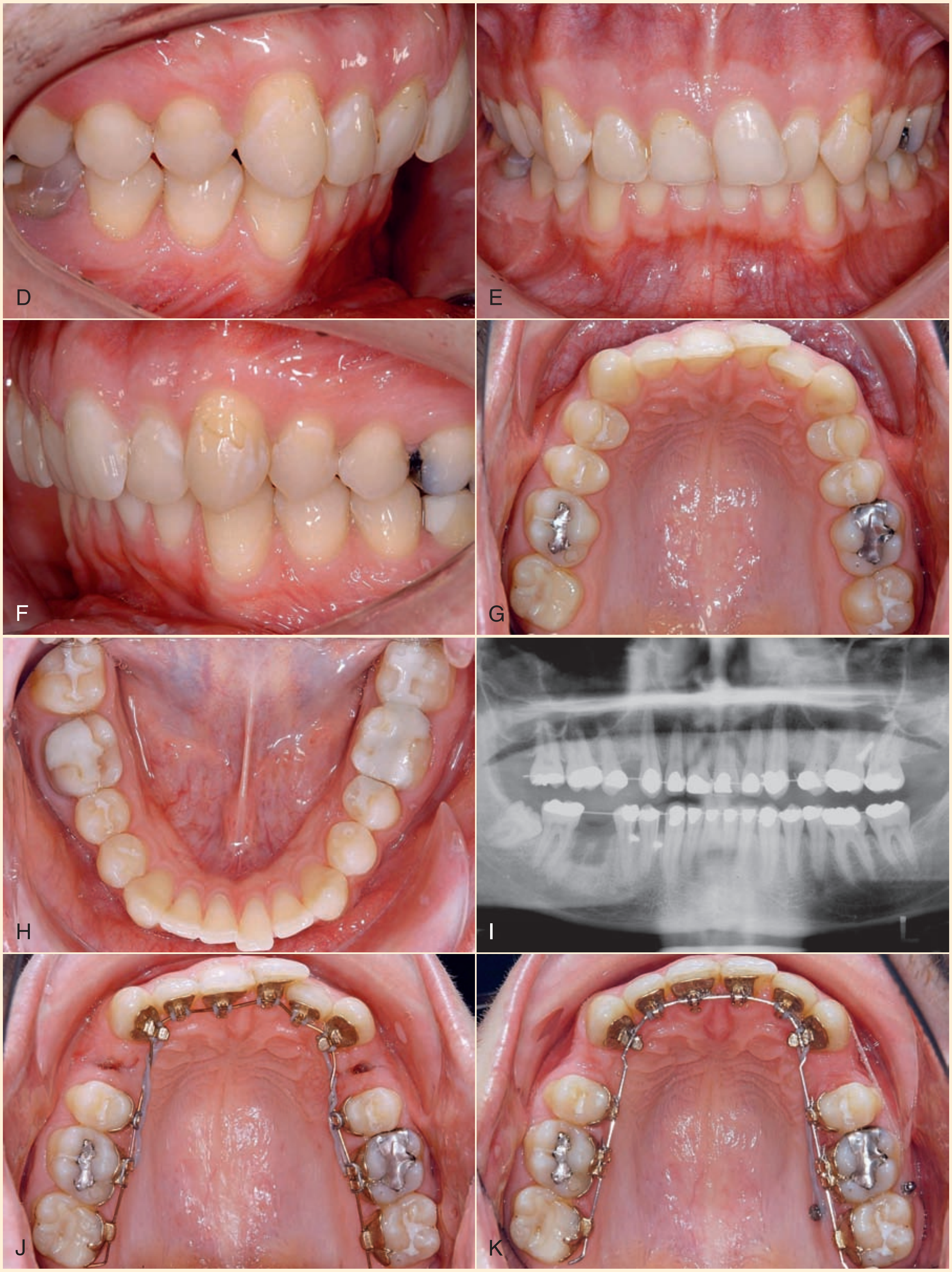

FIGURE 18-18, cont'd **I,** The radiograph shows the situation after insertion of two mini-screws in the upper and the lower jaw just before the start of en masse retraction. The third molar is impacted. **J,** Leveling and aligning. **K,** En masse retraction with double cable mechanics on the patient's left side.

CASE STUDY 18-1 LINGUAL TREATMENT OF ADULT PATIENTS—cont'd

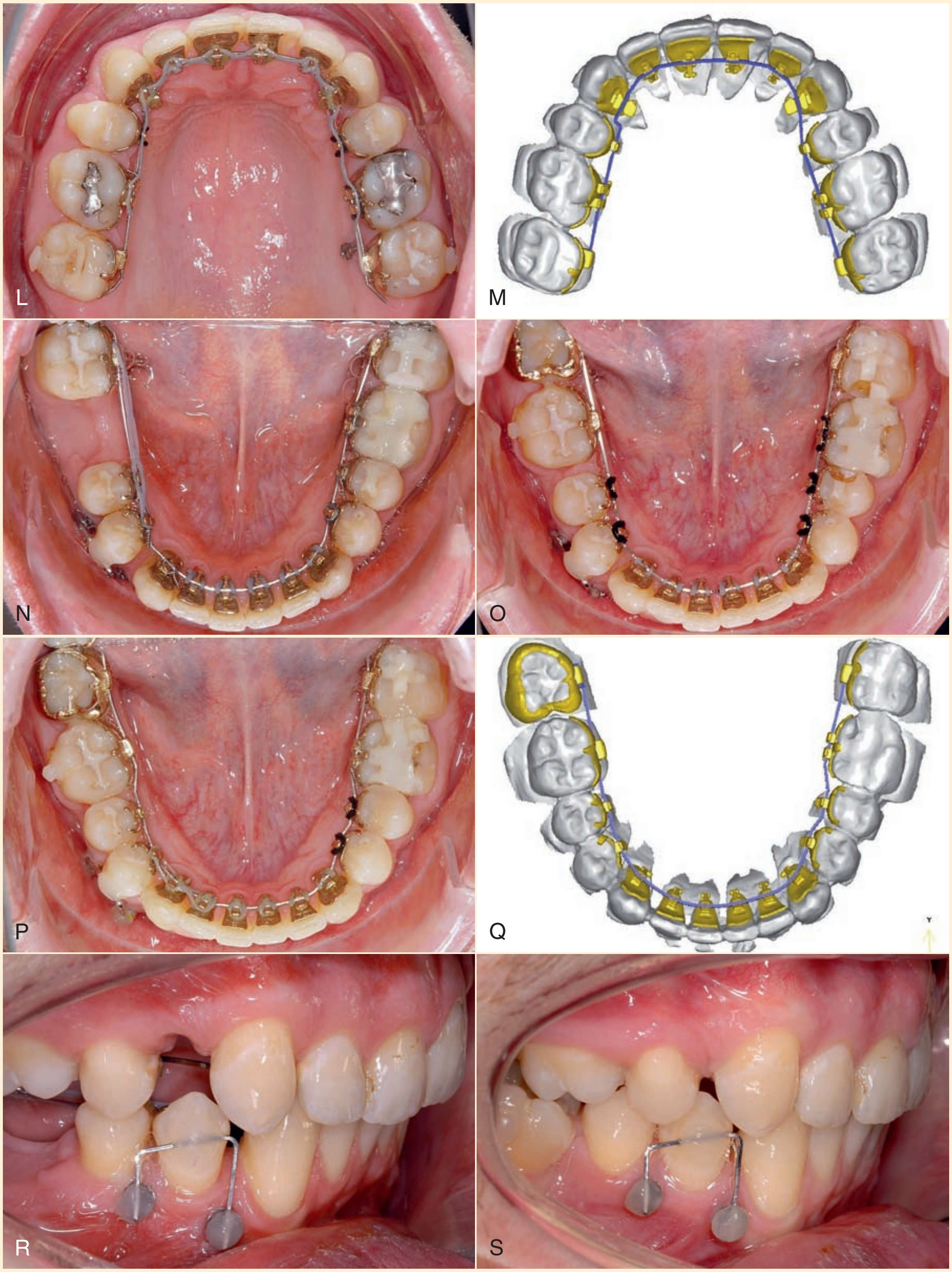

FIGURE 18-18, cont'd **L, M,** Final result and digital treatment plan look similar. **N, O,** Lower arch: beginning and end of en masse retraction. **P, Q,** Final result and the digital treatment plan look similar. **R, S,** Beginning and end of space closure.

Continued

CASE STUDY 18-1

LINGUAL TREATMENT OF ADULT PATIENTS—cont'd

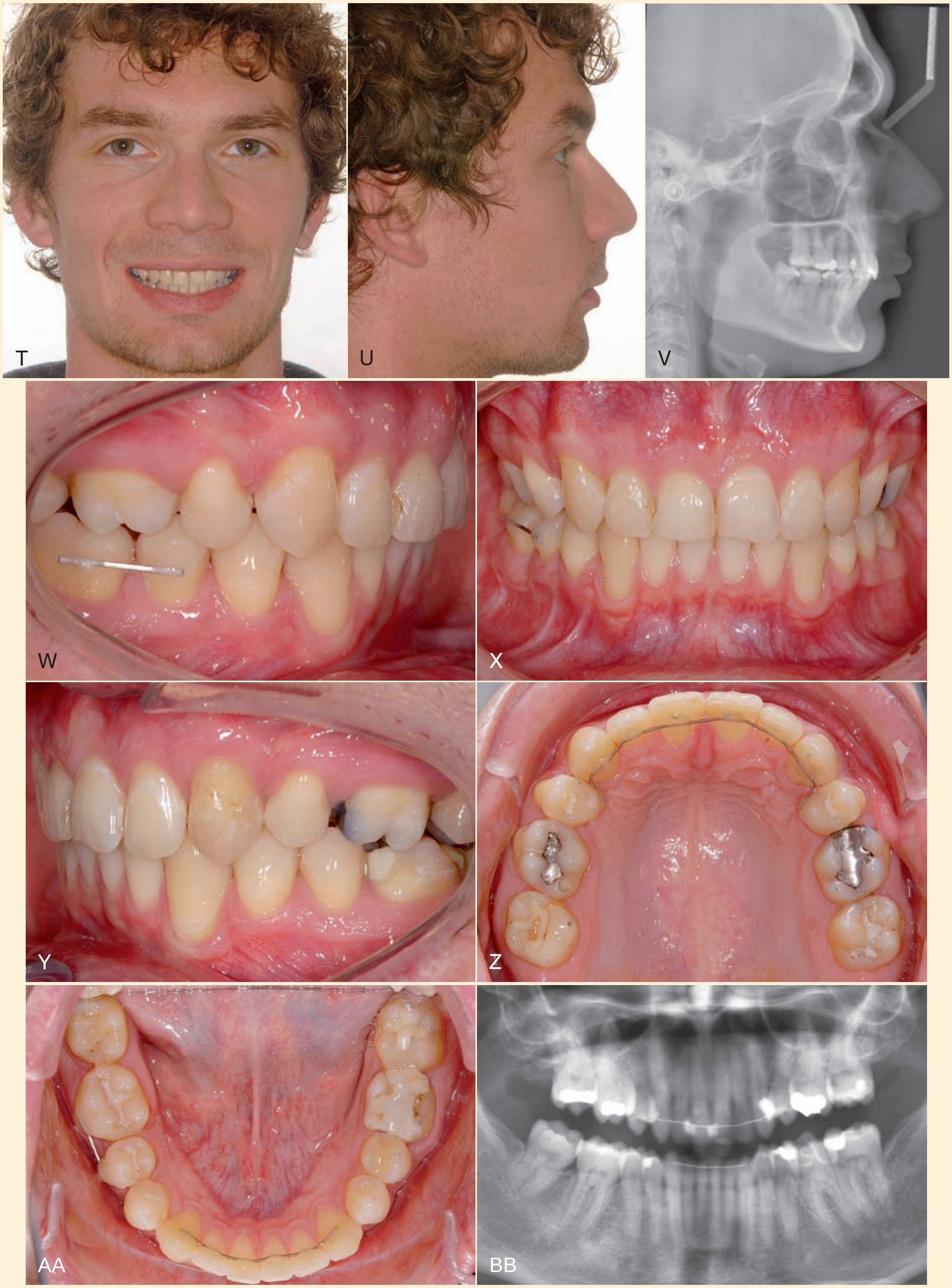

FIGURE 18-18, cont'd **T-BB,** Final results with Class I canine relationship and improved upper anterior torque despite the extractions. The lower right third molar is now in a good position.

CASE STUDY 18-2

LINGUAL TREATMENT OF CHILDREN AND ADOLESCENTS

Nonextraction Case with the Use of Class II Elastics

Dirk Wiechmann

A 13-year-old patient presents with a Class II Division 2 malocclusion with a deep bite (Figure 18-19, *A–I*). The upper anterior teeth display a negative torque. There is mild crowding in the upper and lower anterior segment and small spaces distal to the upper canines. The treatment plan is to align both arches and correct the Class II malocclusion with Class II elastics. Perfect torque control in the upper anterior area is essential. In contrast to adult patients, in children and adolescents the upper and lower appliances are bonded at the same appointment. Because the upper and lower second molars do not expose a sufficiently large bonding area on the lingual aspect, the bracket bases are extended onto the occlusal surfaces (Figure 18-19, *J, N*).

Alignment in the maxilla is initially with a 0.016-inch round superelastic NiTi, followed by a 0.016- × 0.022-inch superelastic NiTi (Figure 18-19, *J*). In the second phase of treatment, a 0.016- × 0.024-inch stainless steel archwire is used for further torque correction (Figure 18-19, *K*). Therefore, the archwire includes extra torque in the upper anterior region. During this phase, Class II elastics extending from the hooks on the upper canines to buccal buttons on the lower

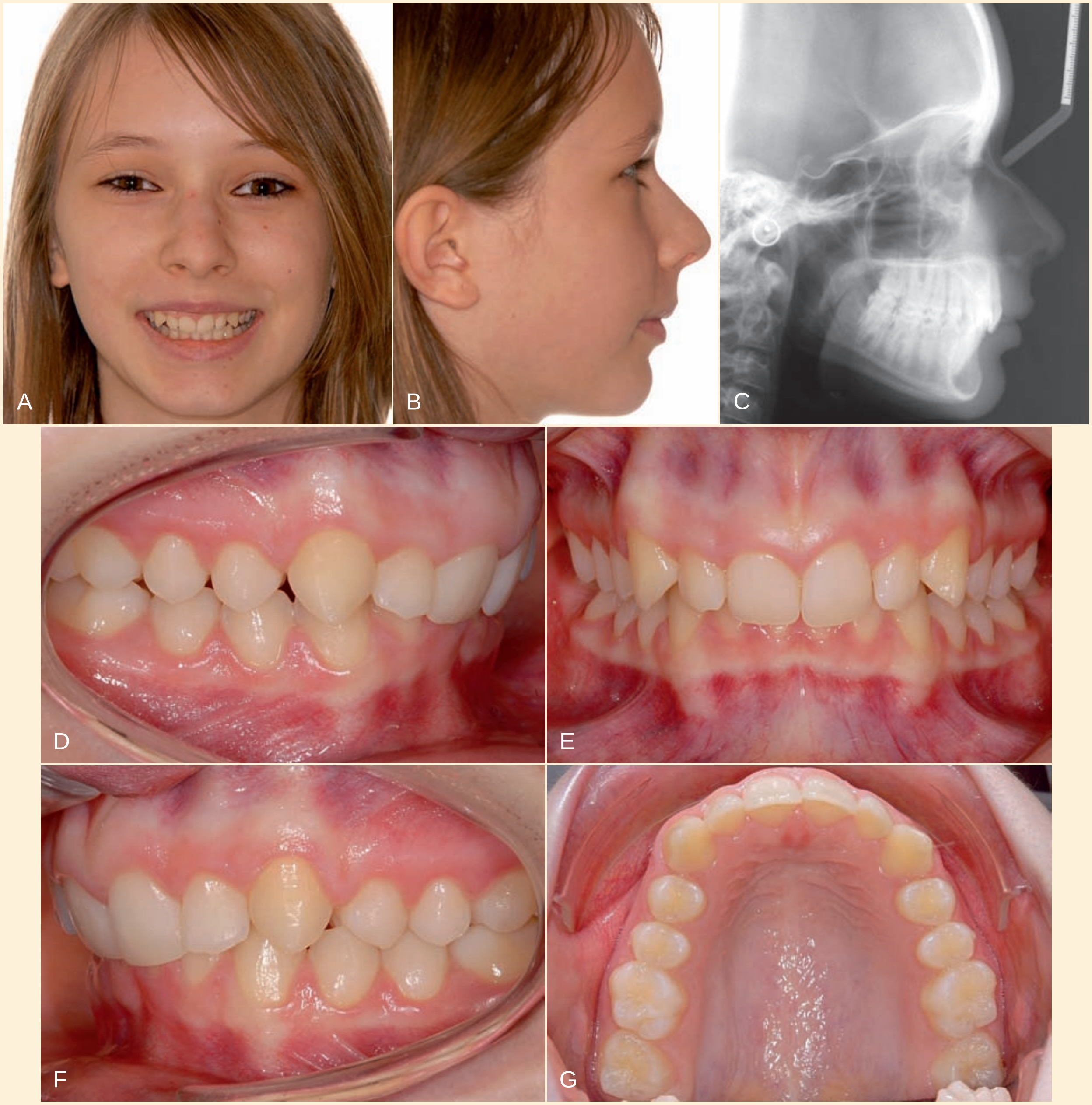

FIGURE 18-19 **A–I,** Nonextraction treatment of a 14-year-old patient with a Class II Division 2 incisor relationship and deep bite. A dentoalveolar compensation is planned with Class II elastics.

Continued

CASE STUDY 18-2 LINGUAL TREATMENT OF CHILDREN AND ADOLESCENTS—cont'd

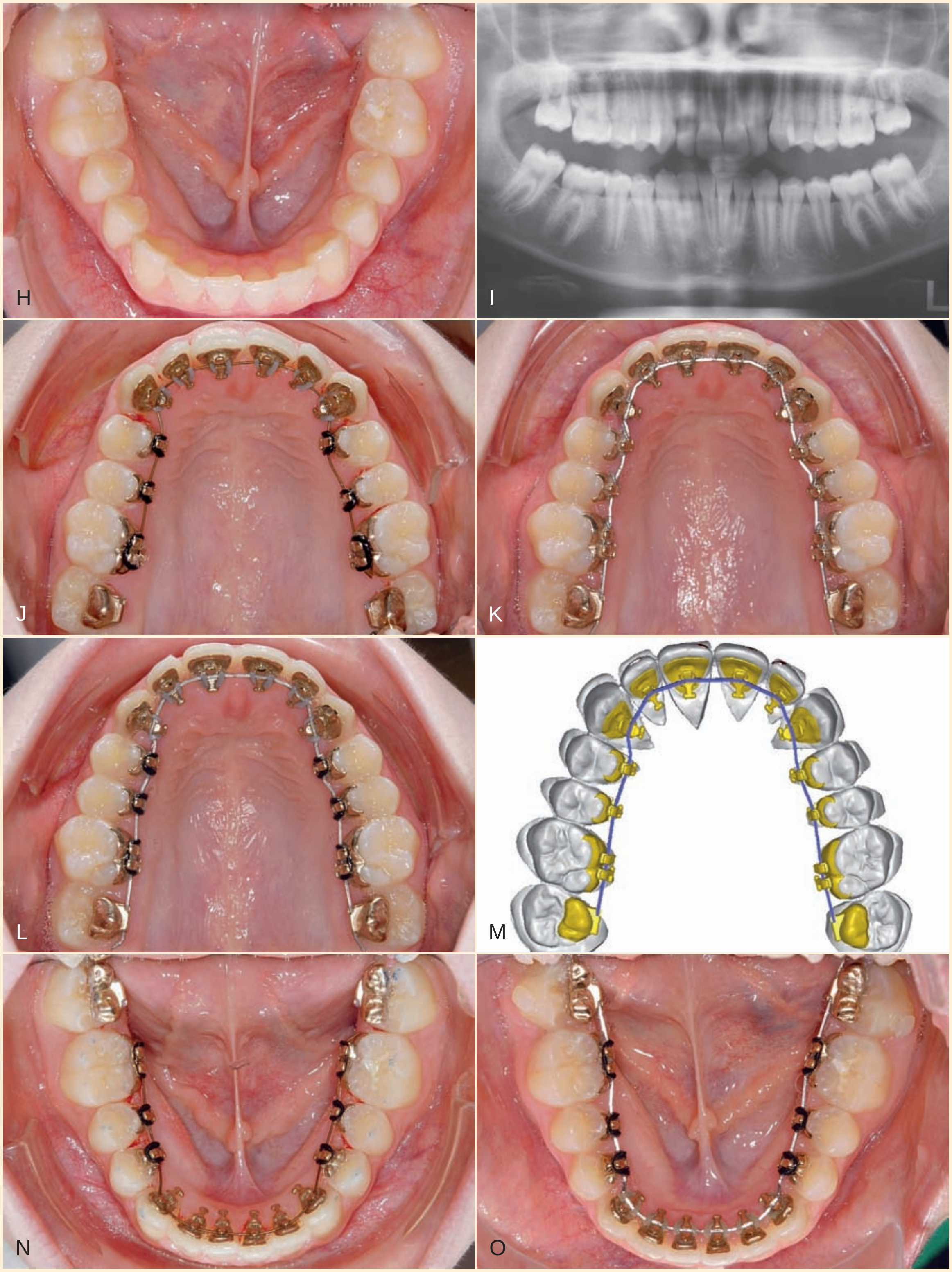

FIGURE 18-19, cont'd **J–M,** Treatment progression in the upper arch. **N–Q,** Treatment progression in the lower arch.

CASE STUDY 18-2 LINGUAL TREATMENT OF CHILDREN AND ADOLESCENTS—cont'd

second molars are used to correct the Class II malocclusion. In finishing, a full-size beta-titanium archwire is placed to express the full prescription. In this case, no further archwire bending by the orthodontist was necessary. The final arch form is similar to the treatment plan (Figure 18-19, *L, M*). In the lower arch, a 0.014-inch round superelastic NiTi archwire is used for initial alignment. The archwire is inserted into the accessory self-ligating slot in the anterior segment (Figure 18-19, *N*). To improve patient comfort, thin NiTi archwires are not extended to the second molars but adapted with a bend back distal to the first molars. To complete the alignment, a 0.016- × 0.022-inch superelastic NiTi is inserted. As in the upper arch, a 0.016- × 0.024-inch stainless steel archwire is used in the second phase for the correction of the Class II malocclusion. For this purpose, buccal buttons have been bonded to the buccal surfaces of the lower second molars (Figure 18-19, *O*). Finishing is completed on full-size beta-titanium archwires. No supplementary finishing bends had to be placed by the orthodontist. The final arch form looks like the digital treatment plan (Figure 18-19, *P, Q*). In the lateral view, immediate bite opening after bonding can be seen (Figure 18-19, *R, S*). After progressive improvement of the upper anterior torque and Class II correction with Class II elastics, small buccal buttons are used on the patient's right hand side to improve the occlusion during finishing (Figure 18-19, *T*).

Final results after 20 months of treatment are shown in Figure 18-18, *U–EE*. The upper anterior torque is improved by more than 20 degrees. This is not due to simple proclination, because the lateral head film shows a major distal movement of the upper incisor root tips.

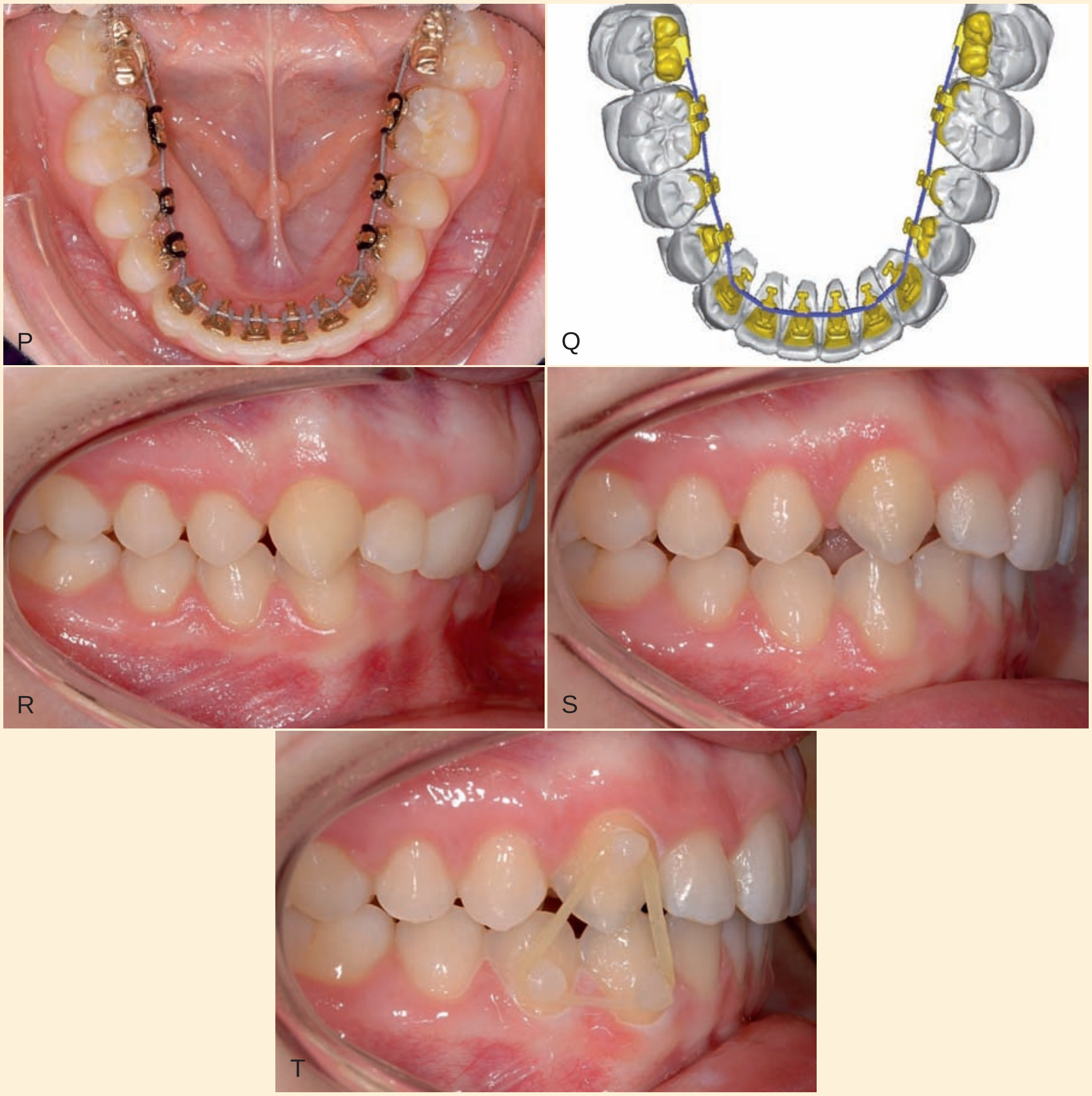

FIGURE 18-19, cont'd **R–T,** Torque and Class II correction in the lateral view.

Continued

CASE STUDY 18-2 LINGUAL TREATMENT OF CHILDREN AND ADOLESCENTS—cont'd

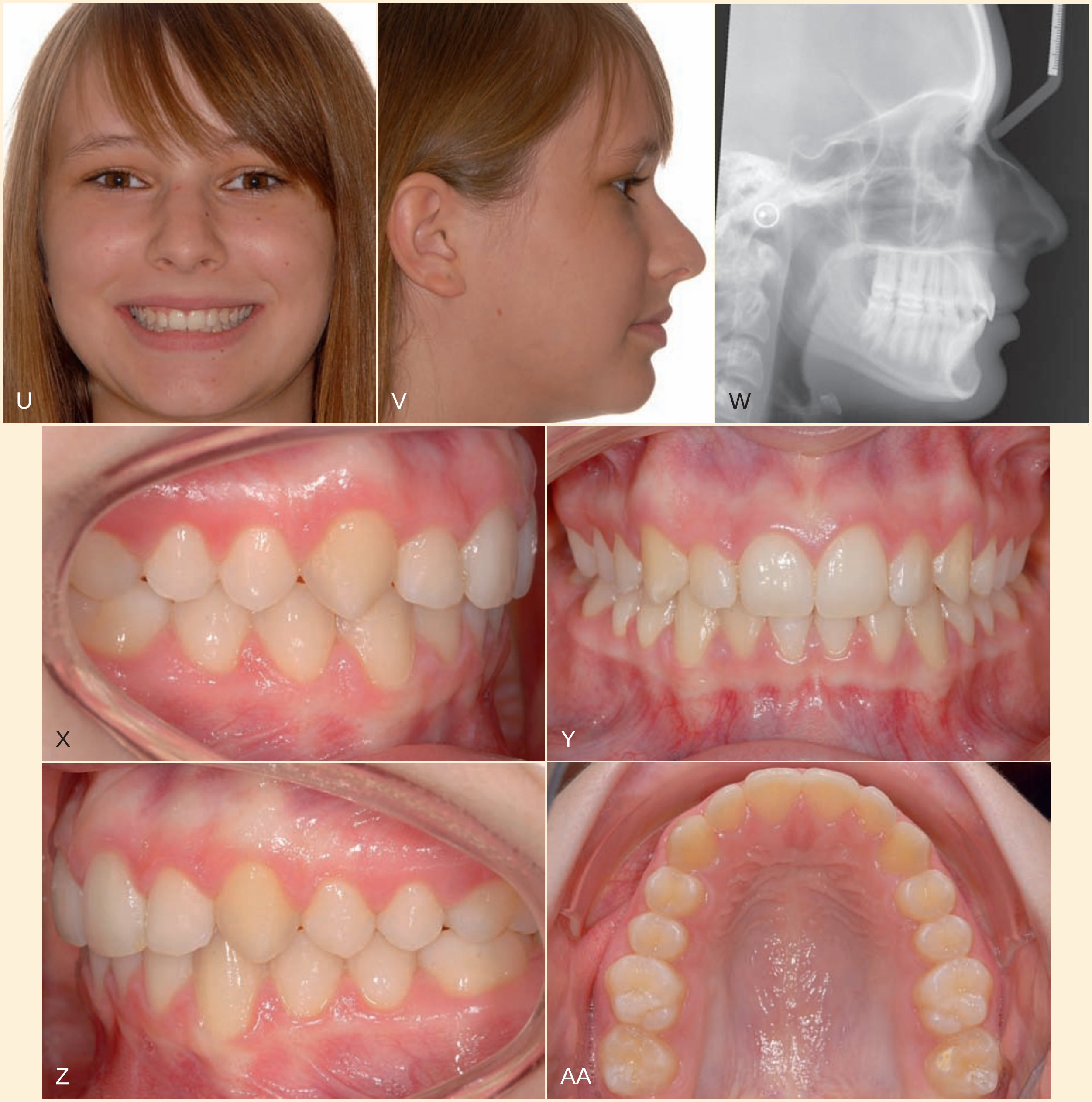

FIGURE 18-19, cont'd **U–EE,** Final results after 20 months of treatment showing excellent torque control in the upper anterior segment.

CASE STUDY 18-2

LINGUAL TREATMENT OF CHILDREN AND ADOLESCENTS—cont'd

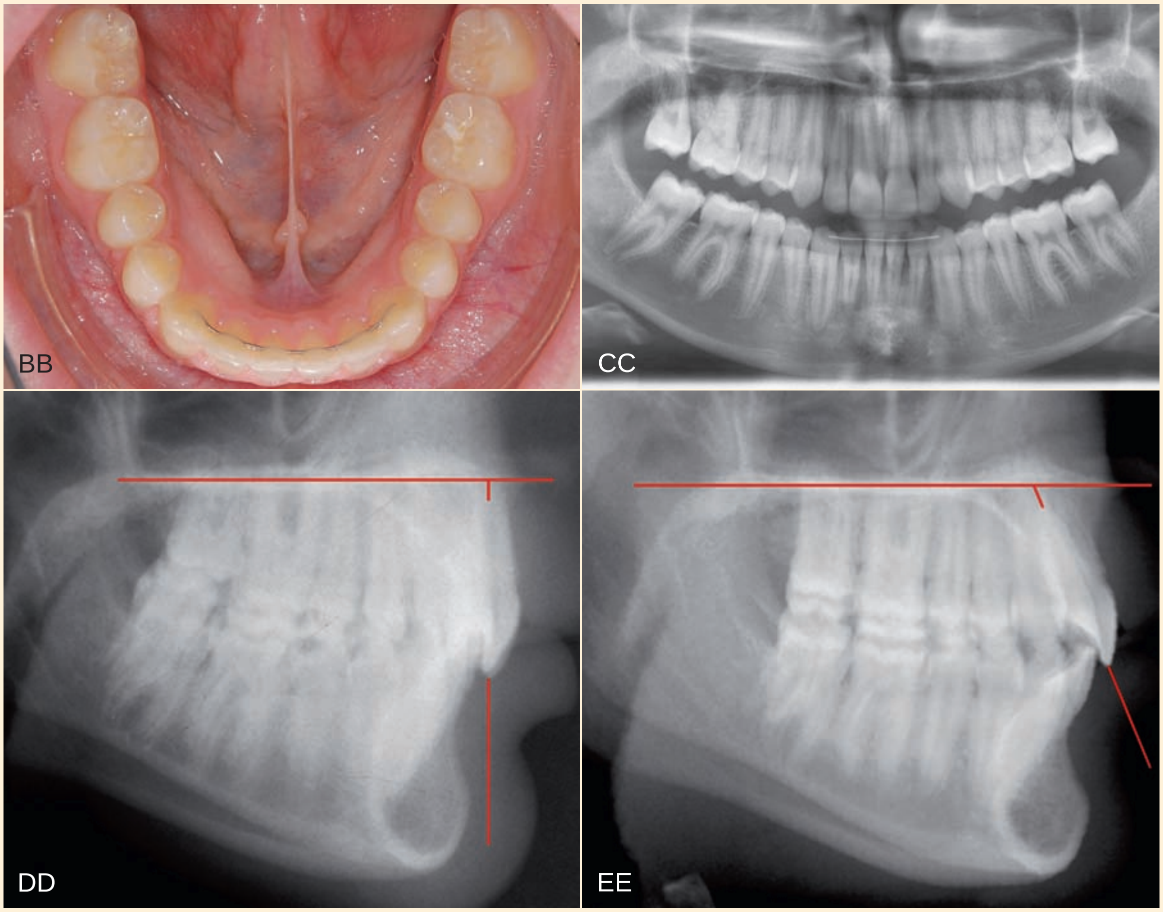

FIGURE 18-19, cont'd

CASE STUDY 18-3

INCOGNITO LINGUAL APPLIANCE

Herbst Functional Appliance

Dirk Wiechmann

A 14-year-old patient presents with a Class II malocclusion with crowding (Figure 18-20, *A–I*). The lower anterior teeth are proclined. The treatment plan is to expand the upper arch, upright the lower incisors, and correct the Class II malocclusion by dentoalveolar compensation using a Herbst device.[20,22,28]

Initially, a band with a buccal Herbst rod is bonded on the upper first molars (Figure 18-20, *J*). Leveling and aligning are started on a 0.016-inch round superelastic NiTi archwire that is adapted distal to the first molars. In the anterior region, an overtie is used to prevent the archwire from slipping out of the slot. A 0.016- × 0.022-inch and a 0.018- × 0.025-inch superelastic NiTi complete the first phase of treatment and prepare for the insertion of a full-size stainless steel archwire (Figure 18-20, *K*). During the Herbst phase, a 0.018- × 0.025-inch stainless steel archwire is used (Figure 18-20, *L*). This rigid full-size archwire ensures reliable arch form control and makes the use for a transpalatal arch obsolete. The archwire is bent back vertically behind the second molar to prevent space opening. The final archwire is a full-size beta-titanium archwire. No extra archwire bending is necessary. The arch form is similar to the digital treatment plan (Figure 18-20, *M, N*).

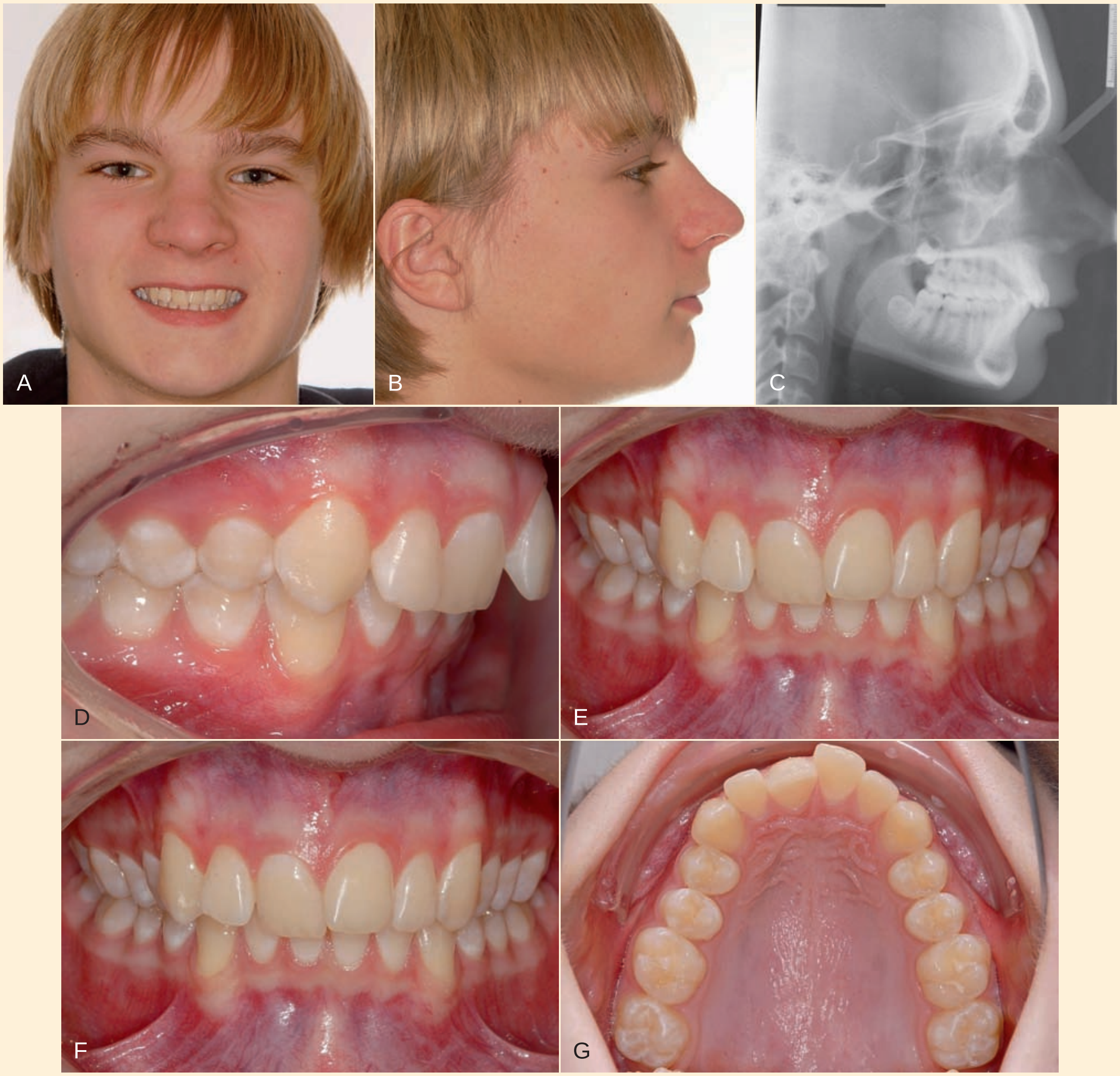

FIGURE 18-20 **A–I,** Combined Incognito/Herbst treatment of a 14-year-old patient with a Class II relationship and proclined lower incisors.

CASE STUDY 18-3 INCOGNITO LINGUAL APPLIANCE—cont'd

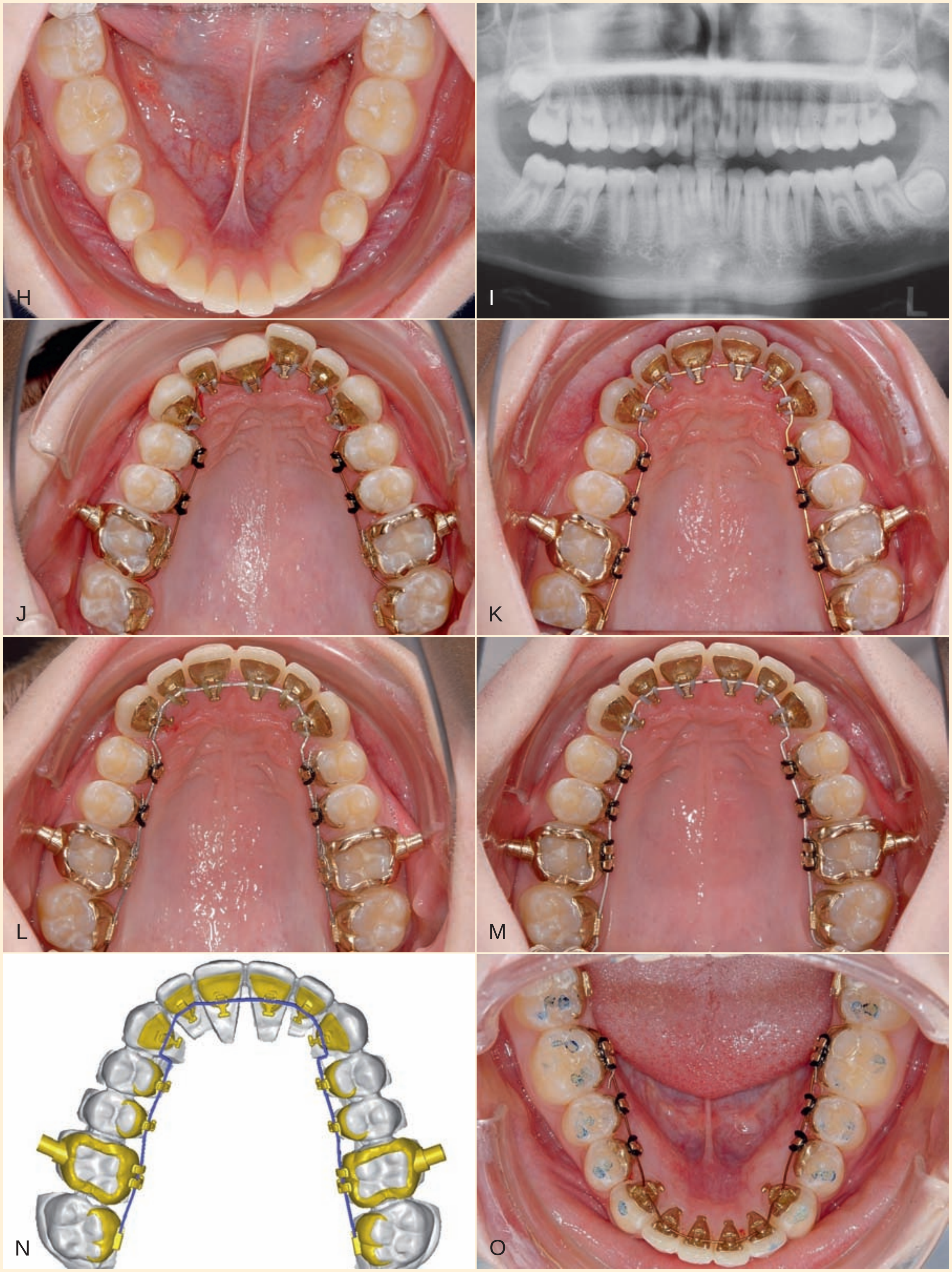

FIGURE 18-20, cont'd **J–N,** Treatment progression in the upper arch. **O–S,** Treatment progression in the lower arch.

Continued

CASE STUDY 18-3 **INCOGNITO LINGUAL APPLIANCE—cont'd**

Aligning in the lower arch starts with a 0.014-inch round superelastic NiTi archwire, which is inserted into the accessory self-ligation slot in the lower anterior segment (Figure 18-20, *O*). The archwire is bent back distal to the first molars. A 0.016- × 0.022-inch archwire followed by a 0.018- × 0.025-inch superelastic NiTi archwires are used to complete leveling and aligning. Overties are used for ligation in the anterior segment (Figure 18-20, *P*). When the 0.018- × 0.025-inch stainless steel archwire is inserted, the canine attachments are changed for bands with buccal Herbst rods. A power chain is used to prevent space opening during the Herbst phase (Figure 18-20, *Q*). When the final finishing archwire is inserted, the buccal parts of the lower canine bands are cut off. Buttons are bonded on the buccal surfaces of the second molars for Class II elastic wear during the night. No extra archwire bending is needed for finishing. The final result and the digital setup look similar (Figure 18-20, *R, S*). The different phases of the bite correction are shown in the lateral view. After leveling and aligning, the patient presents with a full Class II malocclusion (Figure 18-20, *T–Y*). The lower incisors have been uprighted. Activation is carried out in two steps: first, the patient is postured into a Class I relationship for 9 months and, second, into an overcorrected position for an additional 5 months. At the end of the Herbst phase, the lower incisors do not appear to be more proclined than at the beginning of the Herbst phase.[13,28]

Final results after 28 months of treatment are shown in Figure 18-20, *Z–JJ*. Uprighting of the lower incisors is accomplished as planned[20] (Figure 18-20, *II, MM*). For retention, the patient wears a night activator with minimal protrusion together with upper and lower fixed retainers.[22]

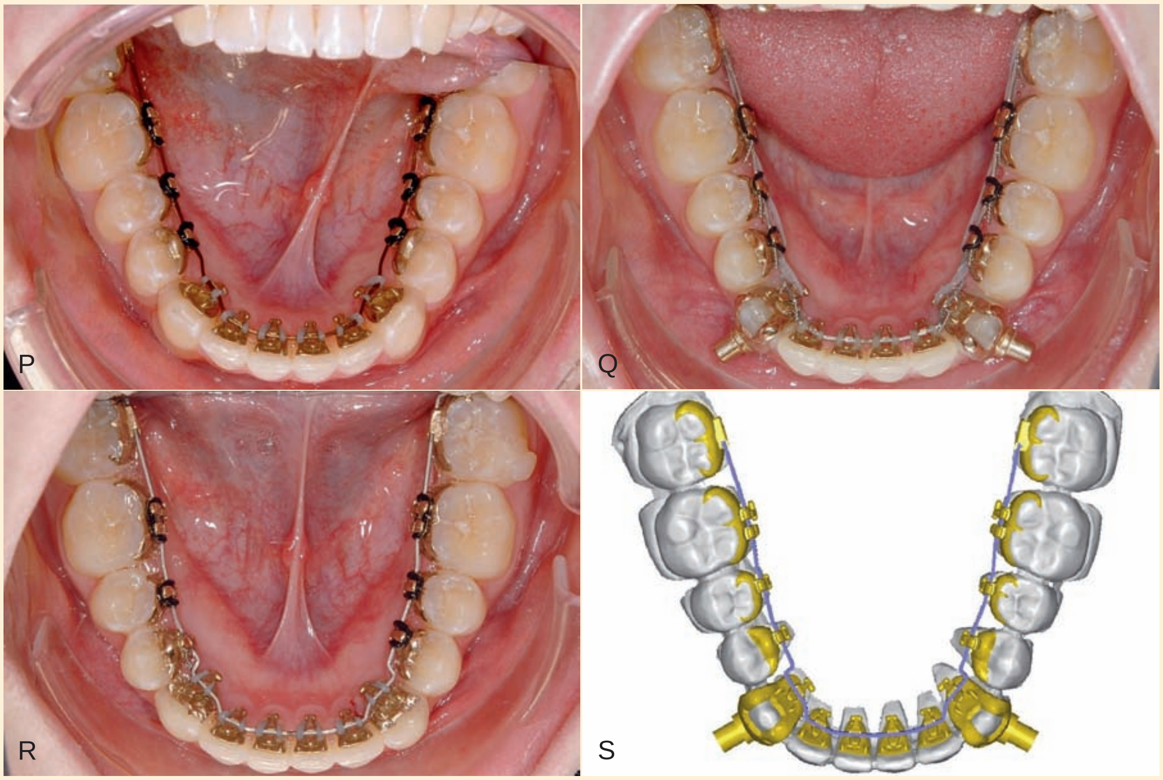

FIGURE 18-20, cont'd

CASE STUDY 18-3 INCOGNITO LINGUAL APPLIANCE—cont'd

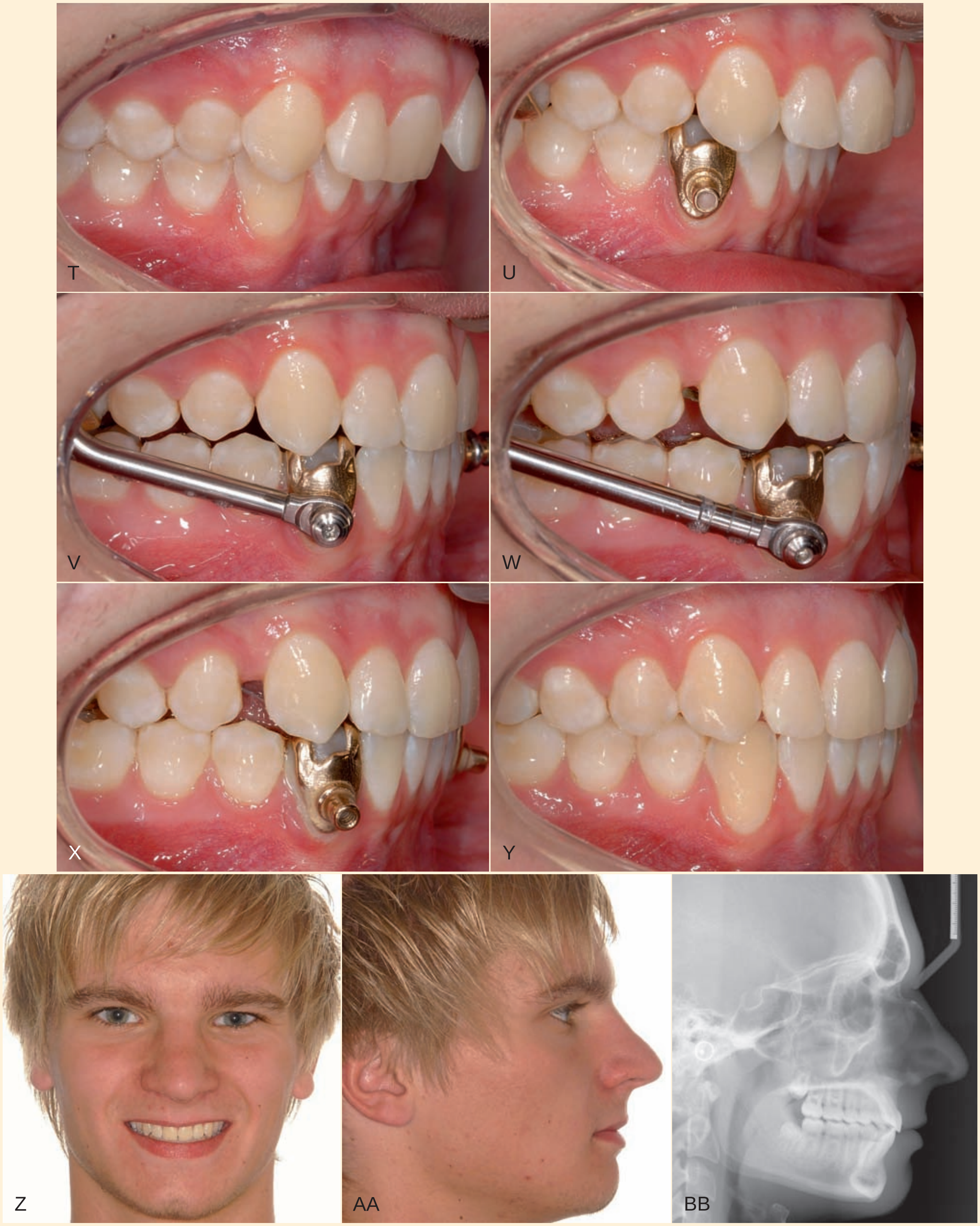

FIGURE 18-20, cont'd **T–Y,** Correction of the Class II relationship. Lower incisors have been uprighted. **Z–JJ,** Final results.

Continued

CASE STUDY 18-3

INCOGNITO LINGUAL APPLIANCE—cont'd

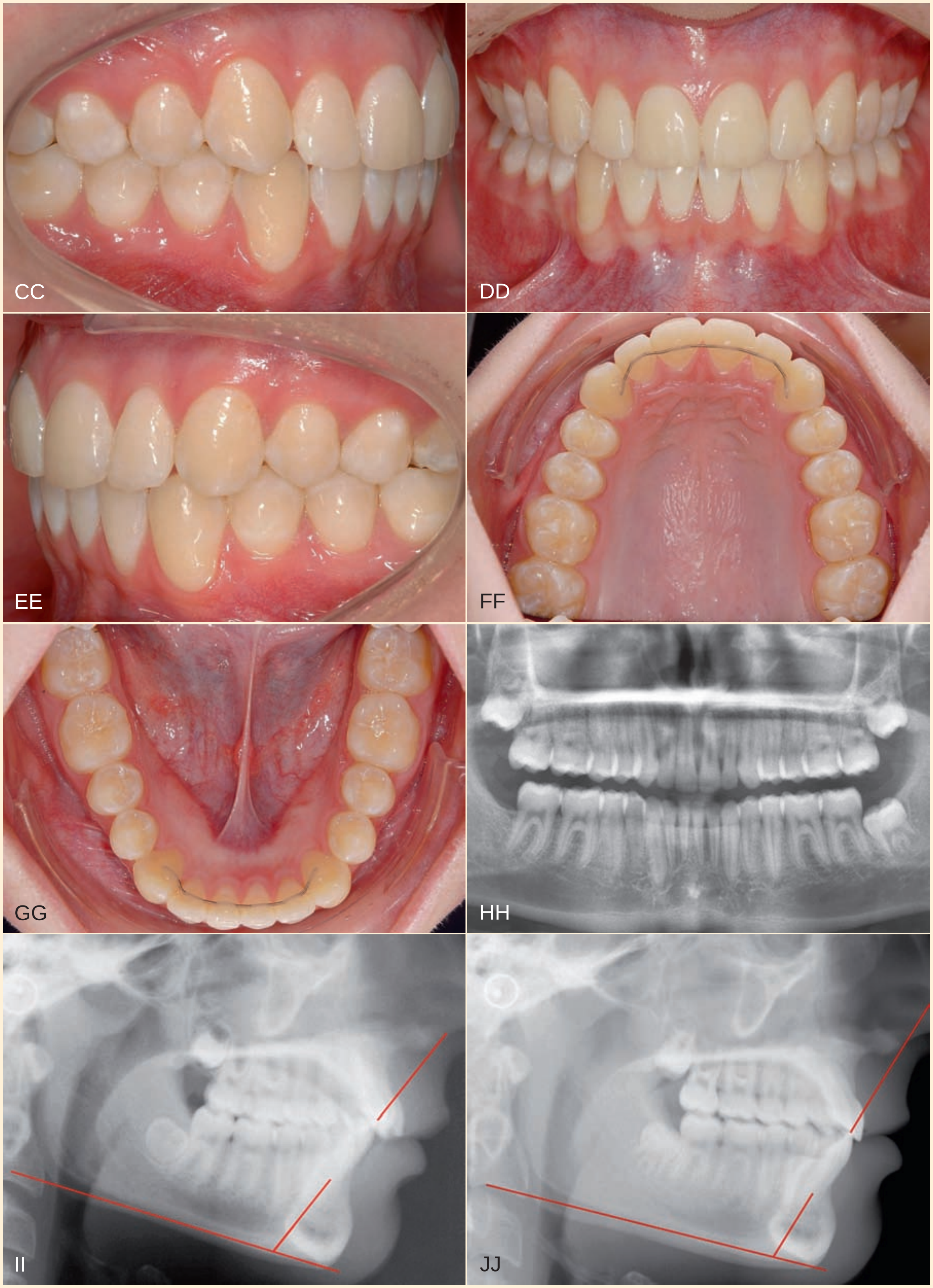

FIGURE 18-20, cont'd

CASE STUDY 18-3 **INCOGNITO LINGUAL APPLIANCE—cont'd**

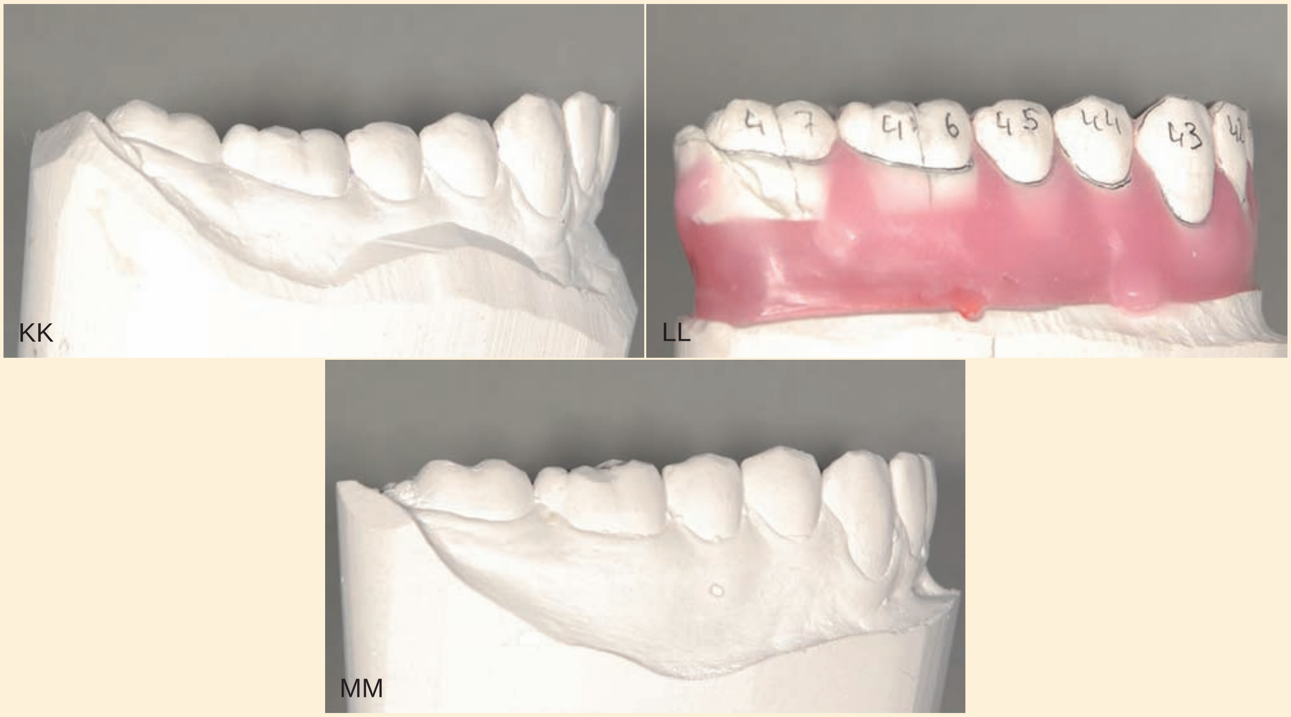

FIGURE 18-20, cont'd **KK,** Situation before start of treatment. **LL,** The individual treatment plan (target setup) shows that lower incisor uprighting is planned. **MM,** The final result.

SUMMARY

Completely customized lingual appliances have revolutionized lingual orthodontics in recent years. Reduced risk of decalcification, superior third-order control, and the undisputed potential to realize exactly the individual treatment plan and transfer this prescription into the patients' mouth along with the possibility to treat children and adolescents will lead to a better acceptance of lingual appliances in orthodontics. However, within the triad of orthodontist, patient, and appliance, which is of such great importance in any orthodontic therapy, even an ideal appliance, alone, will still not offer any guarantee of a successful treatment outcome. It is the knowhow of the orthodontist that finally and always determines the results.

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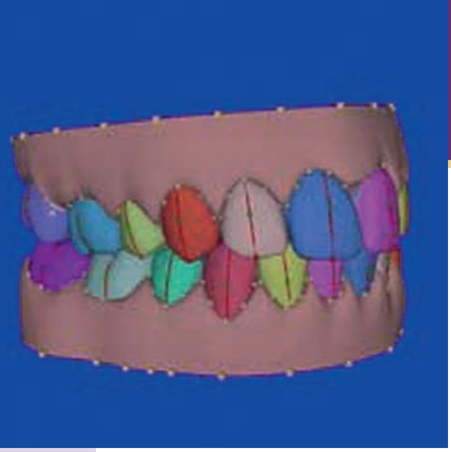

CHAPTER

19

Clear Aligner Treatment

David E. Paquette

OUTLINE

A Brief History of Clear Aligner Treatment
Impression Techniques and Digitization
  Troubleshooting Problems with Impressions
  The Virtual Setup
  Direct Digital Manufacturing
  ClinCheck
Interproximal Reduction and Aligner Treatment
  Staging
Biomechanics of Aligner Treatment
  Simple versus Difficult Movement
Attachments, Power Ridges, and Auxiliaries
  Controlling Torque
  Root Parallelism
  Rotations
  Extrusions
  Invisalign Teen
  Periodontal Considerations
Summary

Invisalign is an orthodontic technique that uses a series of computer-generated custom plastic aligners to gradually guide the teeth into proper alignment. As a technique, it has been commercially available for a decade.

A BRIEF HISTORY OF CLEAR ALIGNER TREATMENT

Clear aligner treatment is not new. Clear aligner treatment falls into two basic categories. The first category consists of those thermoformed appliances, sometimes known as Essix Retainers (Raintree Essix, Dentsply Corp., York, PA), that are fabricated by making adjustments to the tooth positions on plaster or stone models and fabricating one or more aligners to correct a minor malocclusion. These types of appliances are oftentimes fabricated in the orthodontist's office or sometimes sent out to commercial laboratories to be made under a trademarked name such as Simpli 5 (Simpli 5 Express Aligner System, Ormco Corp., Orange, CA). These types of in-office prepared aligner systems have been in use since around 1994. The second category and the focus of this chapter is Invisalign (Align Technology, Inc., Santa Clara, CA). Invisalign is a proprietary orthodontic technique that uses a series of computer generated custom plastic aligners to gradually guide the teeth into proper alignment. Invisalign is both a brand name and a technique and is used synonymously. Although there have been one or two commercially available alternatives to provide patients with a method for comprehensive malocclusion correction using clear aligners in the past, currently Invisalign is the only computer-aided design and manufacturing (CAD-CAM) precision aligner product available in the United States. The reader will understand that although Invisalign is a trademarked commercial name, it is commonly understood by orthodontists to represent a specific technique as well and it will be used throughout the rest of this chapter interchangeably.

As a technique, Invisalign has now been commercially available to orthodontists since 1998. The company and the technique was the brainchild of two graduate business students at Stanford University in 1997, Kelsey Wirth and Zia Chishti. As the story goes, both were given Essix retainers to correct some minor orthodontic relapse and were struck by the same question: "Why couldn't I have had these instead of braces?" Their orthodontists both told them that it was only for very minor problems and dismissed the possibility of correcting complex malocclusions with aligners as nonsense. Unencumbered with any "baggage" of an orthodontic background, they formed a company (Align Technology, Inc.) to attempt to use CAD-CAM to mass produce aligners that would be capable of treating a broader range of malocclusions. They were fortunate in

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attracting the interest of Robert Boyd, chairman of the Department of Orthodontics, University of the Pacific. He assisted in this endeavor by being a consultant, and in doing so he and his residents provided a means to test this fledgling technology.

The concept on which the Invisalign system is based has been around since the 1940s. In 1945, H.D. Kesling[1] suggested that a series of tooth positioners be used to produce the types of movements that are needed for orthodontic treatment. Some years later, Nahoum[2] described a method to change tooth contours using thermoformed plastic. In 1971, Pontiz[3] introduced a thermoformed plastic appliance called the "invisible retainer" made on a master model that prepositioned teeth with base-plate wax. He claimed that this appliance could produce limited tooth movement. McNamara and others[4] also described using invisible retainers to achieve minor tooth movement. Sheridan and others[5] later developed a technique involving interproximal tooth reduction and progressive alignment using clear Essix appliances, and those techniques were further developed by Hilliard and Sheridan[6] with a series of special thermoforming pliers designed to enhance specific movements. Although these techniques based on Kesling's proposal of using removable appliances have been used to some degree in the past, the laboratory construction has always been tedious and had previously limited the widespread adoption of removable aligner techniques.

The removable orthodontic aligner technique has now become a contemporary treatment alternative that orthodontists may offer their patients since Align Technology, Inc. developed the combined computer technology and custom manufacturing processes.

The Invisalign treatment has a terminology that differs from traditional fixed appliances. A *midcourse correction* involves a temporary pause in treatment while new impressions are made; treatment is then continued once new aligners are fabricated. The reasons for midcourse correction could be lack of patient compliance; mid treatment restorative that rendered the current set of aligners unusable due to tooth morphology; lack of one or more teeth tracking with aligners as planned, making the fit of the aligners unacceptable; or a change in the treatment plan. Many orthodontists consider midcourse correction to be similar in concept to repositioning brackets partway through treatment with fixed appliances. Another term unique to aligner treatment is *refinement*. Refinement is similar to midcourse correction in that it generally involves pausing treatment and taking new impressions and ordering a new series of aligners. The only difference is that refinement takes place near the end of treatment when it is apparent that one or more teeth are not positioned exactly as desired. This could be due to small amounts of permanent distortion of the aligners so that the actual tooth positions do not match the virtual treatment plan or it could be because there was insufficient attention to details during the virtual setup phase. In any event, in order to achieve the desired results, another series of aligners is required. Refinement can be considered similar to artistic detail bends with fixed appliances. Another term used more frequently with aligner treatment than with fixed appliances is *interproximal reduction*. This involves the process of removing controlled amounts of tooth structure interproximally and will be discussed at length later in the chapter. The final term unique to aligner treatment is *attachment*. Attachments are small composite additions to the tooth surface to enhance areas of undercut either for retention or to facilitate specific movements. Attachment design and placement also will be discussed in detail later in the chapter.

IMPRESSION TECHNIQUES AND DIGITIZATION

Treatment success begins with a high-quality polyvinyl siloxane (PVS) impression. Initially, Align Technology used a process called *destructive scanning* to produce the three-dimensional (3D) digital image of the patient's teeth. It involved pouring the impressions with plaster to produce a conventional 3D model. Those models were then "scanned" using a destructive technique whereby the model was photographed from the occlusal view, milled down slightly, photographed again, milled down some more, photographed again, etc. When this process was completed, the computer software would then use the series of digital photographs to reassemble the layers and recreate the model virtually by stacking the images. The destructive scanning method had the advantage that a lab technician could fix minor imperfections in the impression by repairing the model prior to scanning. The disadvantage was that it was expensive and time consuming and produced huge quantities of plaster dust. Align Technology no longer uses the destructive scanning technique but converts the impression directly into a 3D virtual model by means of a high-resolution industrial computed tomography (CT) scan. The special plastic impression trays must not interfere with the x-ray scanning and there is no plaster model intermediary on which a lab technician can repair defects, so the impressions must be perfect.

There are three basic impression techniques:

1. The easiest but most likely to result in defective impressions involves a one-step impression using a suitable "medium body" PVS material in the proprietary Invisalign impression trays. Many orthodontists prefer this method because of the potential for reduced chair time and expenses. The problem with this one-step technique is that there is a higher probability of missing the critical anatomy of one or more teeth, especially the areas distal to the second molars which are required for proper fit of the aligners. Figure 19-1 illustrates an unacceptable impression.

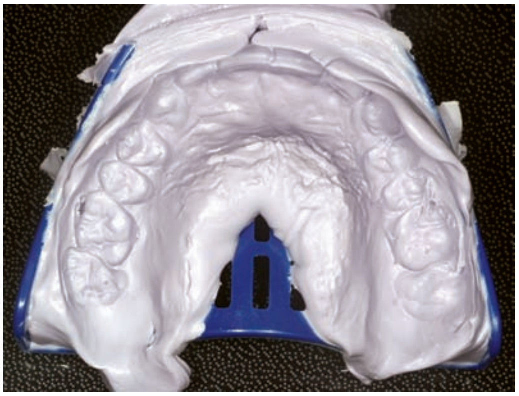


FIGURE 19-1 Unacceptable impression.

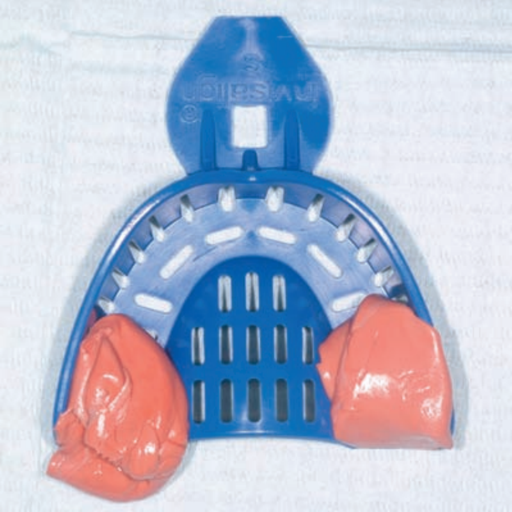


FIGURE 19-2 Putty technique step one.

2. The second impression technique that can be used is a combination technique wherein impressions of the second molars are first captured using a PVS putty material to create a posterior dam. The medium body material is used over the putty to gain a more detailed impression of the second molars, as well as to capture the rest of dentition. Figures 19-2 to 19-4 illustrate impressions using this technique. Although this technique takes more chair time, the advantage is that it reduces the probability of having an unacceptable impression.
3. The third impression technique involves a more involved two-step process. The first step involves making custom trays and Essix-type retainers that we later describe to the patient as "training aligners." When the patient elects to start treatment, an alginate impression is taken of both arches. The patient is then scheduled to return for final impressions. The rest of the first step is completed in the laboratory. The impressions are poured up in the office using standard dental stone and trimmed as though they were to be used to make Essix-style retainers (Figure 19-5).

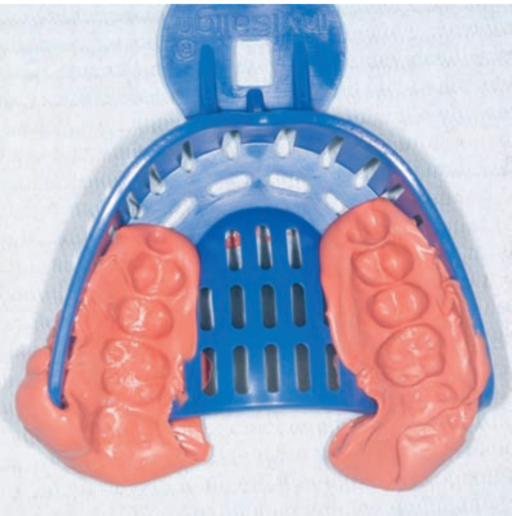


FIGURE 19-3 Putty technique step two.

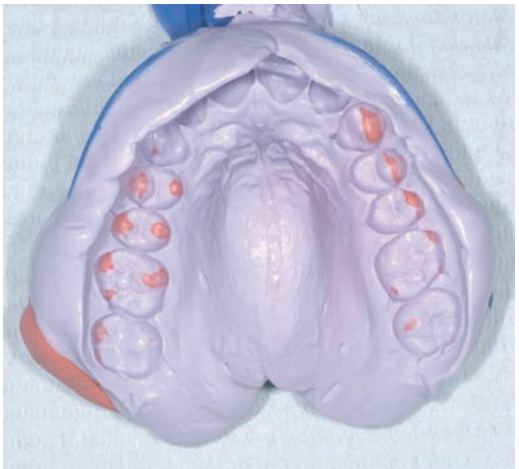


FIGURE 19-4 Putty technique final.

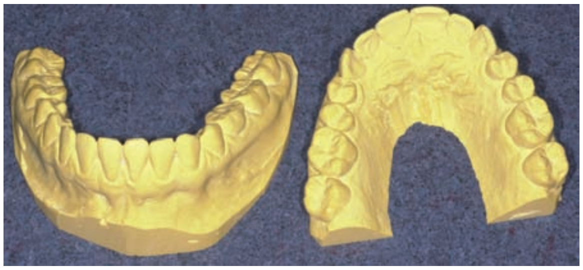


FIGURE 19-5 Initial stone models.

Then the thermoformed plastic material is formed over the models but not trimmed (Figure 19-6).

While the full sheet of thermoformed plastic material is still on the stone model, a plastic impression tray is sized and then filled with the heavy body or putty PVS material of your choice, and the model with untrimmed thermoformed plastic material is inverted and pressed down into the impression material. The reason for pressing the model into the impression material and not vice versa is to ensure good visualization to produce a consistent thickness of impression material around the teeth, creating a perfect custom tray. It is important to make sure the distal of the second molars are captured in the custom tray (Figures 19-7 to 19-9).

Once the custom tray is made, the thermoformed plastic material is trimmed in a typical manner and will be used as the patient's "training aligner."

The next step involves the final impression when the patient returns to the office for the final PVS impressions, which are made by placing a minimal amount of a fast set light body wash inside the custom tray (Figures 19-10 and 19-11).

Once the impressions are made, the patient receives the training aligners and, if he or she is interested in bleaching the teeth, the training aligners may be used while awaiting the arrival of aligners from Align.

Troubleshooting Problems with Impressions

The aligner fit is only as good as the quality of the impressions.

The most common shortcoming with impressions is failure to capture sufficient detail of the distal of the second molars. With no distal surface of the terminal molars, the retention of the appliance is compromised because it simply floats on the surface of the distal molars, so when certain forces are applied to the anterior teeth, the appliance is easily dislodged. These errors can be avoided by using one of the two-step impression techniques described previously.

A common error is multiple areas of "drag" near the gingival margin. These are triangular voids caused by seating the tray with impression material too quickly into the mouth and not allowing sufficient time for the material to flow around the gingival margins. This is a critical error because there is no way to have the appliances properly trimmed for comfort and effectiveness if the gingival margins cannot be identified. This can be avoided by seating the impression tray more slowly (Figure 19-12).

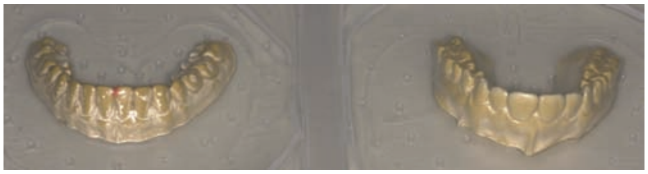


FIGURE 19-6 Models with thermoformed plastic material in place.

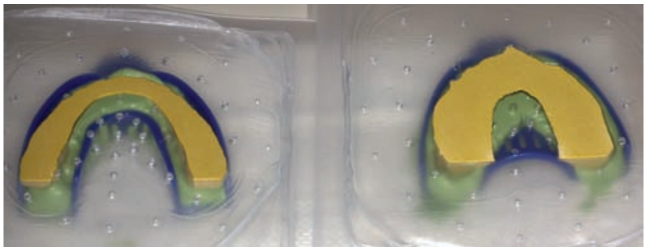


FIGURE 19-8 Models with thermoformed plastic sheet inverted into heavy body material.

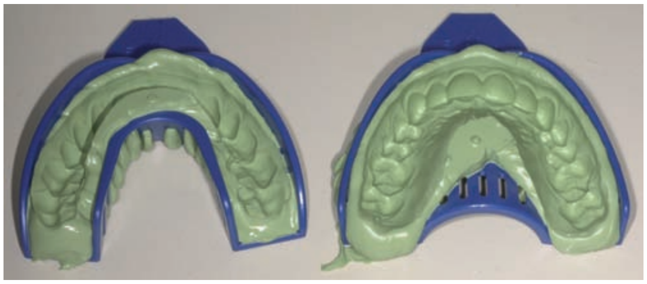


FIGURE 19-9 Completed custom trays.

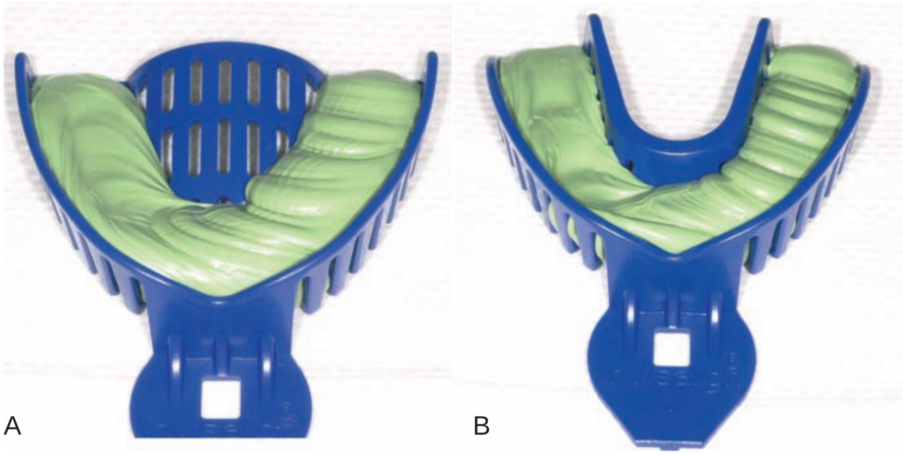


FIGURE 19-7 **A, B,** Plastic impression trays with heavy body material.

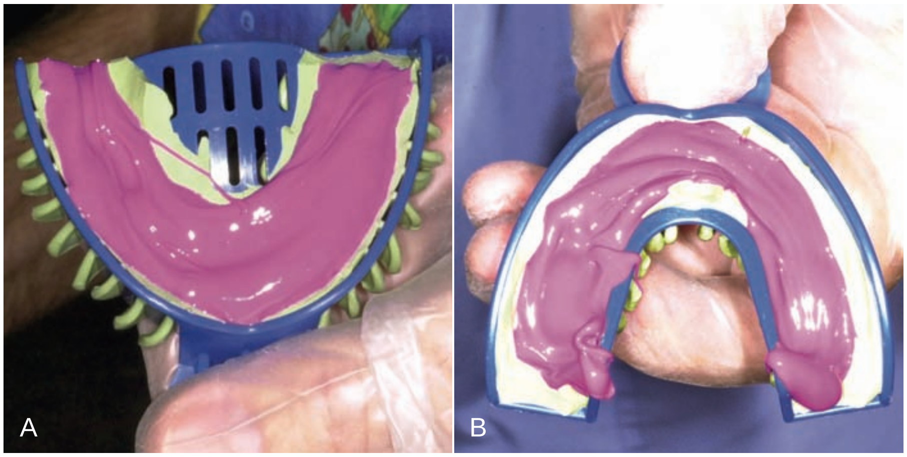


FIGURE 19-10 **A, B,** Custom trays with light body wash ready for final impression.

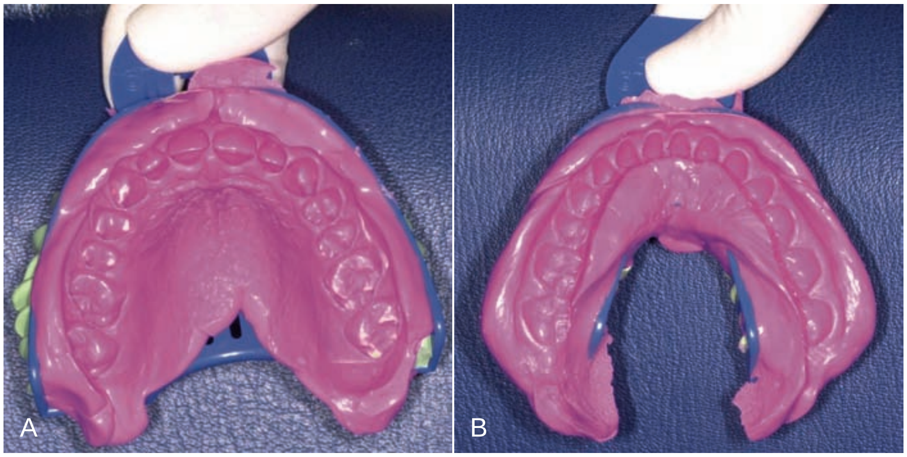


FIGURE 19-11 **A, B,** Completed final impressions.

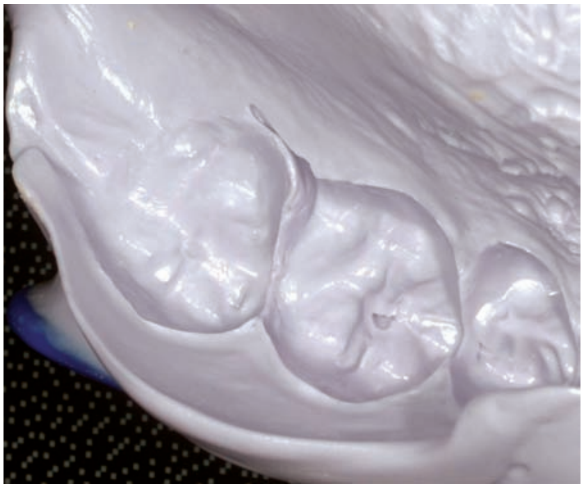


FIGURE 19-12 Drag defects near gingival margins.

A third common error involves surface or immediate subsurface air bubbles in the impression. These are created either by capturing air in folds of the material while loading the tray due to moving the syringe tip in and out of the material or by seating the impression tray too quickly into the mouth and trapping air between the tooth and the material. If the air bubble is immediately below the surface of the impression material, the impression may appear to be of good quality, but when it is scanned with the CT, the PVS material may not be of sufficient thickness to be resolved on the image and the tooth will have a large area of distortion on the virtual model. Both these errors can be avoided by using proper technique (Figure 19-13).

The last common error is seating the impression tray too far from or too close to the buccal or lingual tooth surface so that the impression material bleeds through to the impression tray and the material becomes too thin to be resolved on the CT image. These errors produce a virtual model with the same problems as an air bubble. This can be avoided by using the correct size impression tray and seating it properly in the mouth. It should be noted that the impression trays that are provided by Align Technology are plastic and are easily customized to the patient by heating the tray and forming it to the individual patient's arch form (Figure 19-14).

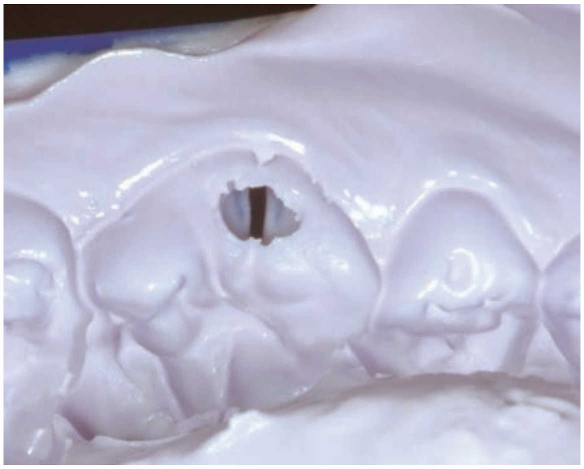


FIGURE 19-13 Air bubbles in the impressions.

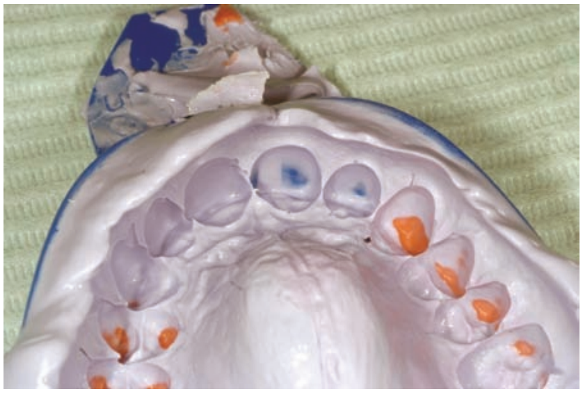


FIGURE 19-14 Impression tray bleed through.

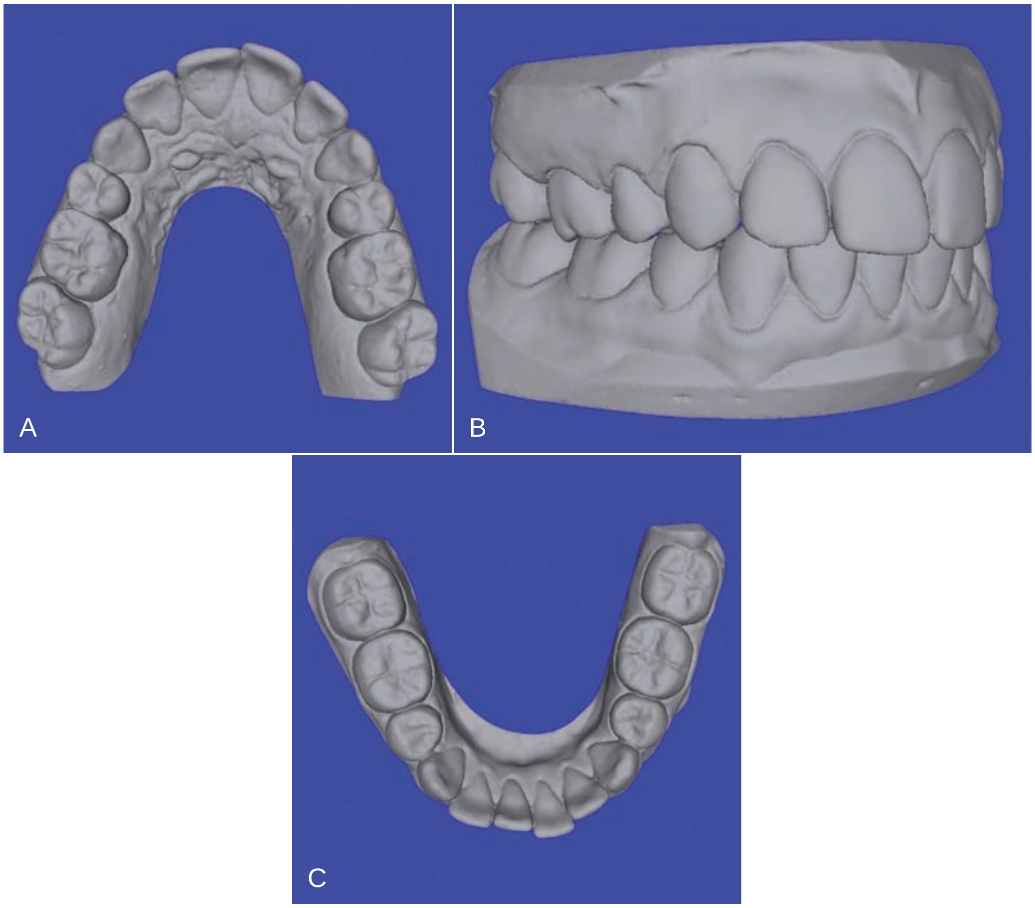


FIGURE 19-15 **A–C,** Three-dimensional virtual models generated from CT scan of PVS impressions.

The Virtual Setup

When the impressions arrive at Align Technology in Santa Clara, California, they are scanned using an industrial CT scan to produce a 3D virtual model. The technician uses a best-fit occlusion based on wear facets and virtual contacts along with the intraoral photographs provided in the submission kit to articulate the models. It is important to understand that the occlusal registration sent with the impressions is used to verify the occlusion only if the photographs are of poor quality (Figure 19-15).

Once the virtual models are produced, they are segmented using boundary recognition software to define individual teeth. It is important to remember for future discussion that the impression generally does not capture the interproximal surfaces of the teeth, so the software must interpolate that information and estimate the location of interproximal surfaces and contact areas. Once that is accomplished, virtual "roots" are placed (Figure 19-16).

The technicians recreate the virtual gingival margins using morphing-type software to mimic the gingival conditions seen on the clinical photographs (Figure 19-17).

The preparation work is finished at this point, and the virtual model is forwarded electronically to the TREAT (Align Technology, Inc.) operator to perform the virtual setup and staging. TREAT is the proprietary software that Align Technology uses to simulate treatment and set up the virtual model to allow the manufacture of the aligners. It is a sophisticated 3D graphics program that gives the operator great control of tooth position and rate of tooth movement. It is not the software that the orthodontist uses to view the virtual model, which is called ClinCheck (Align Technology, Inc.) and will be discussed later in this chapter. Once the virtual setup is completed and approved by the orthodontist, a series of plastic models is fabricated using stereolithography on which the aligners are then made by a thermoforming process.

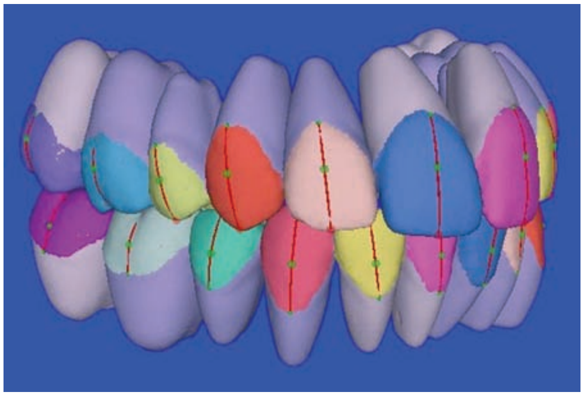


FIGURE 19-16 Tooth segmentation.

Direct Digital Manufacturing

Due to the time and expense of producing PVS impressions, shipping them to Align Technology, scanning them once received, and subsequent processing of the image data into a usable format, there is emphasis on finding a method of direct digital conversion of the dentition into a usable 3D image. Currently, there are two promising technologies: cone beam CT (CBCT) and intraoral light scanners. Both of these technologies have the potential of producing an image that would be of a sufficiently high quality that the orthodontist would be able to capture the image directly in their office and then electronically transmit that image to Align Technology to have the appliances made. The advantage of direct digital capture of the dentition would be (1) the elimination of the need for PVS impressions and their inherent potential for clinical errors and (2) reducing the time needed to produce appliances because the image would be transmitted instantly to Align Technology via the Internet. There are still multiple challenges remaining with both approaches. However, prototype appliances have been made using both techniques and it is likely that one or both approaches to direct digital manufacturing will be available in the future.

ClinCheck

The software used by the orthodontist in the office is called ClinCheck (see Figure 19-17). ClinCheck allows the orthodontist to view the treatment in all aspects as well as superimpose one stage of treatment over another to visualize individual tooth movements so as to to gauge the probability of accomplishing the desired movement that will be biologically feasible (Figure 19-18).

The single greatest benefit of ClinCheck is its usefulness as a tool for therapeutic diagnosis. One can prescribe a given treatment plan, such as a nonextraction approach with some expansion and proclination if crowding is present. The outcome may be visualized and compared with treatment using either extractions or

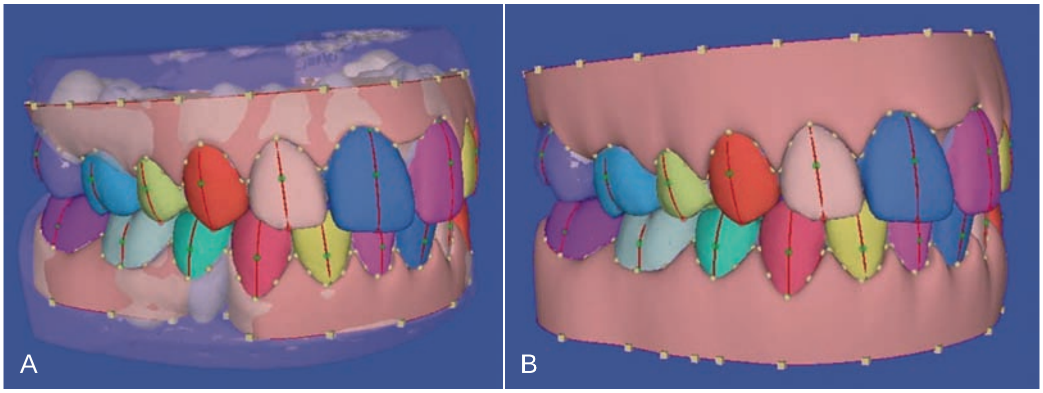
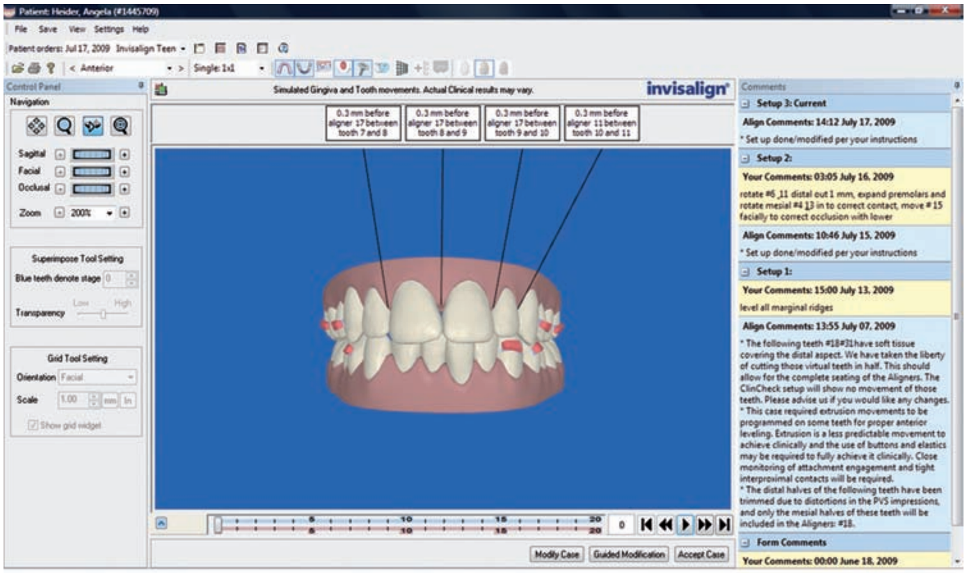


FIGURE 19-17 **A, B,** Gingival contouring.



Patient: Heider, Angela (#1445709)

Patient orders: Jul 17, 2009 Invisalign Teen

Simulated Gingiva and Tooth movements. Actual Clinical results may vary.

Setup 3: Current

Align Comments: 14:12 July 17, 2009

* Set up done/modified per your instructions

Setup 2:

Your Comments: 03:05 July 16, 2009

rotate #6 ,11 distal out 1 mm, expand premolars and rotate mesial #4 13 in to correct contact, move # 15 facially to correct occlusion with lower

Align Comments: 10:46 July 15, 2009

* Set up done/modified per your instructions

Setup 1:

Your Comments: 15:00 July 13, 2009

level all marginal ridges

Align Comments: 13:55 July 07, 2009

* The following teeth #18#31have soft tissue covering the distal aspect. We have taken the liberty of cutting those virtual teeth in half. This should allow for the complete seating of the Aligners. The ClinCheck setup will show no movement of those teeth. Please advise us if you would like any changes.

* This case required extrusion movements to be programmed on some teeth for proper anterior leveling. Extrusion is a less predictable movement to achieve clinically and the use of buttons and elastics may be required to fully achieve it clinically. Close monitoring of attachment engagement and tight interproximal contacts will be required.

* The distal halves of the following teeth have been trimmed due to distortions in the PVS impressions, and only the mesial halves of these teeth will be included in the Aligners: #18.

Form Comments

Your Comments: 00:00 June 18, 2009

FIGURE 19-18 ClinCheck 2.8 user interface.

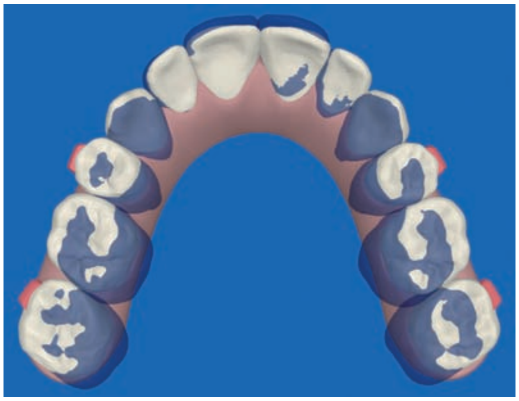


FIGURE 19-19 Superimposition tool showing initial in blue and final in white.

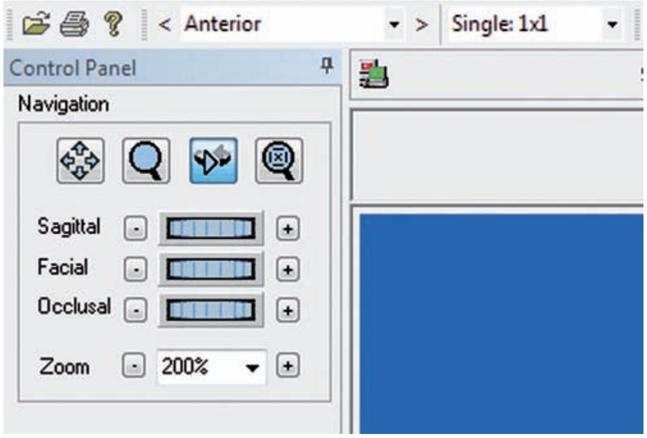


FIGURE 19-20 Virtual model manipulation tools.

interproximal reduction. Although the treatment outcomes cannot be superimposed on each other, they each can be superimposed on the pretreatment virtual model for evaluation (Figure 19-19).

The superimposition tool is only one of the many tools available to the orthodontist for evaluation of potential treatment outcome that will be discussed. The first group of tools is the virtual model manipulation tools located in the upper left of the screen (Figure 19-20). Align Technology has provided the orthodontist with several ways to manipulate the virtual model. The first is to simply left click on the model and manipulate the view with the mouse. Some people have a little difficulty controlling the movements using this method. The next method is the defined views (Figure 19-21). The defined views allow one to click on a predefined viewing angle of the model or proceed through a sequence of views (Figure 19-22) to allow thorough examination of the final occlusion and alignment.

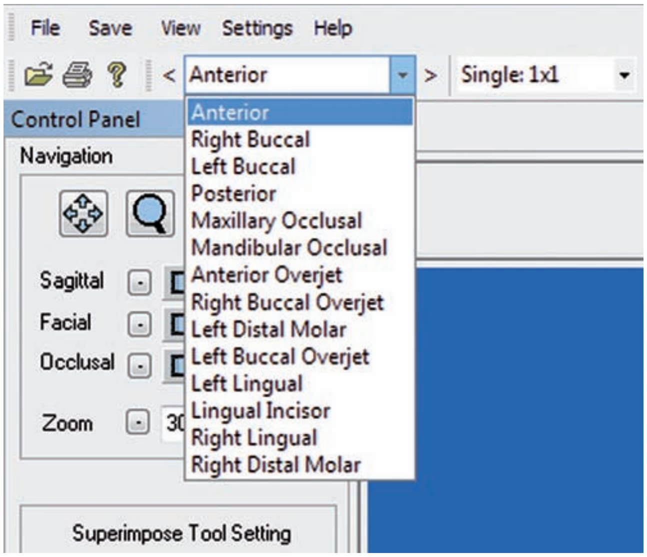


FIGURE 19-21 Predefined views available by one click.

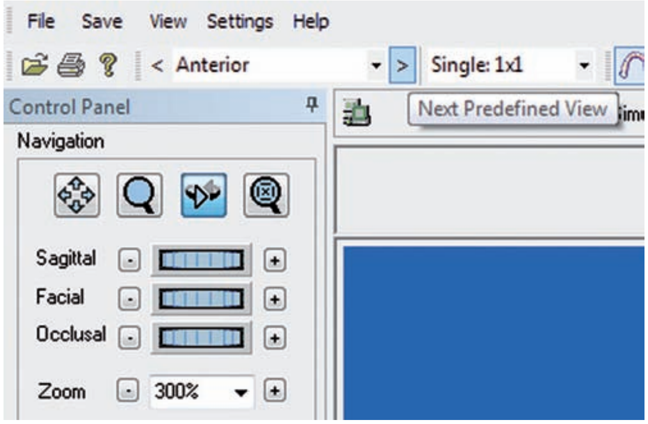


FIGURE 19-22 Predefined views available in sequence (note "Anterior" currently selected).

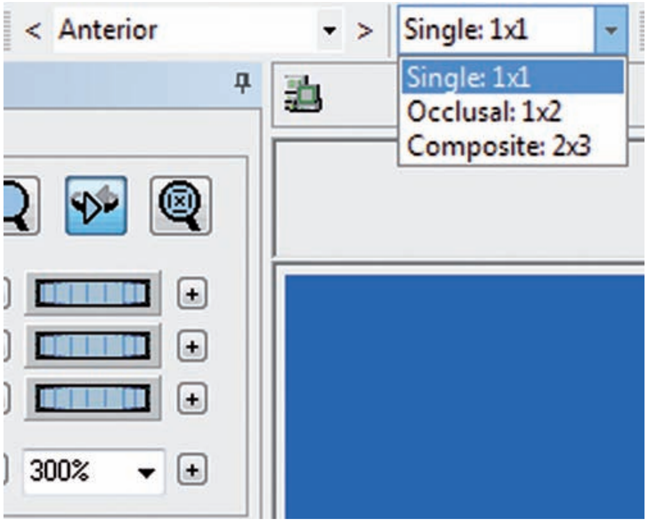


FIGURE 19-23 Gallery views.

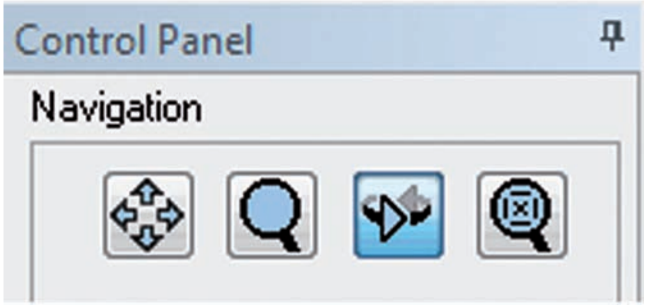


FIGURE 19-24 Navigation buttons.

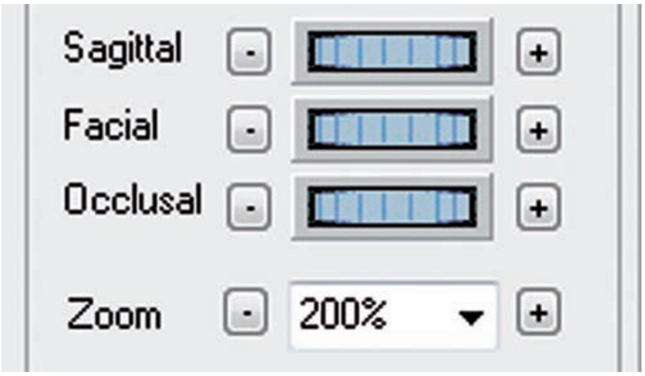
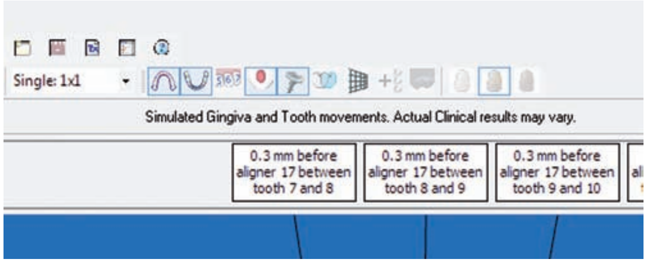


FIGURE 19-25 Navigation wheels and zoom control.



Simulated Gingiva and Tooth movements. Actual Clinical results may vary.

0.3 mm before aligner 17 between tooth 7 and 8

0.3 mm before aligner 17 between tooth 8 and 9

0.3 mm before aligner 17 between tooth 9 and 10

FIGURE 19-26 Illustration buttons.

The next tool available is the gallery views, which allow the orthodontist to view a single model, two arches simultaneously in separate orientations, or a collage of six separate views (Figure 19-23).

Moving down the left side of the interface, there is a group of four navigation buttons that allow the user to move the model around the screen, zoom in or out overall, rotate the model, or zoom into a specific location by clicking the mouse on the desired spot (Figure 19-24).

Below the navigation buttons is a group of three wheels that allow the user another method of rotating the model in any plane of space. Immediately below the navigation wheels is another zoom tool that allows the user to either gradually increase or decrease the size of the model or simply type in the amount of magnification desired (Figure 19-25).

Across the top to the right of the gallery views is a group of illustration buttons (Figure 19-26). These allow the user to show or hide the upper or lower model, tooth numbers, attachments, interproximal reduction recommendations, superimposition, grid tool, overcorrection stages, projected final position for partially erupted teeth, and tooth shade display on screen. These buttons function in an on-off manner simply by clicking the mouse on the desired button. It should be noted that the default setting is for IPR prescription, attachments and comments to be turned on initially, and for the tooth numbering, superimposition, and grid tool to be turned off initially.

An example of the grid tool is shown in Figure 19-27. Note that the widget in the upper left allows the manipulation of the grid orientation. The scale of the grid can be changed as needed and the navigation wheels can manipulate the overall position of the model and grid together. This is a great tool to evaluate symmetry, arch form, spacing for implants or veneers, actual amount of expansion or intrusion, etc. On the lower left is a drop-down menu of tools for adjusting the grid characteristics.

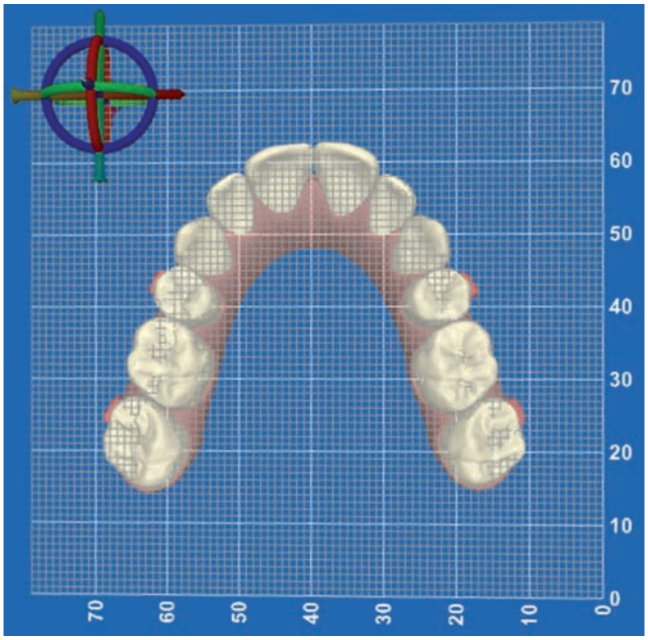


FIGURE 19-27 Grid tool superimposed on occlusal to check symmetry.

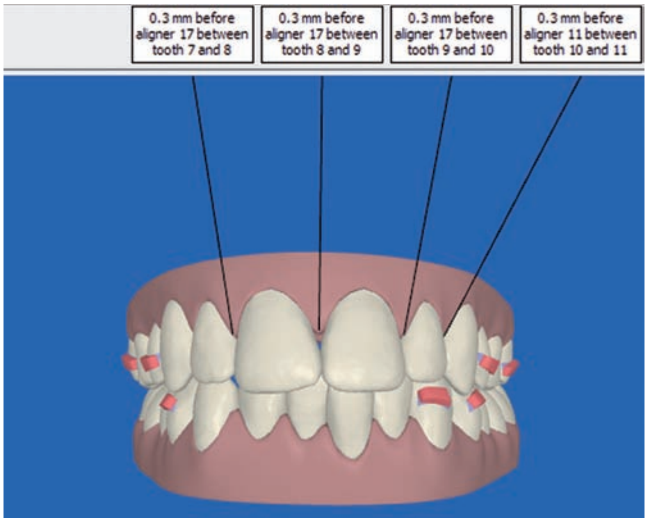
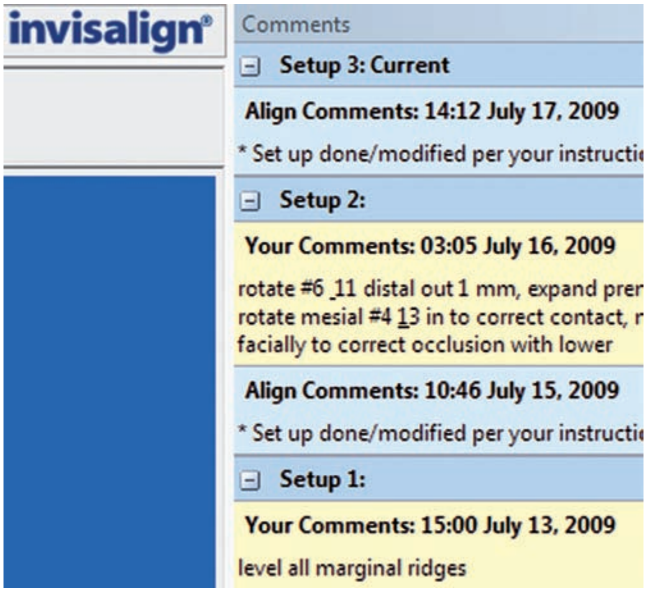

0.3 mm before aligner 17 between tooth 7 and 8
0.3 mm before aligner 17 between tooth 8 and 9
0.3 mm before aligner 17 between tooth 9 and 10
0.3 mm before aligner 11 between tooth 10 and 11

FIGURE 19-28 IPR recommendations.



⊟ **Setup 3: Current**

Align Comments: 14:12 July 17, 2009

* Set up done/modified per your instructi

⊟ **Setup 2:**

Your Comments: 03:05 July 16, 2009

rotate #6 _11 distal out 1 mm, expand prer
rotate mesial #4 13 in to correct contact, r
facially to correct occlusion with lower

Align Comments: 10:46 July 15, 2009

* Set up done/modified per your instructi

⊟ **Setup 1:**

Your Comments: 15:00 July 13, 2009

level all marginal ridges

FIGURE 19-29 Comments section.

Moving to the top center of the screen are the interproximal reduction (IPR) recommendations. The process of IPR will be discussed later in this chapter. The default view is for IPR recommendations to be turned on so that if any are required, they automatically appear unless the user turns them off. The recommendations detail when and where IPR is to be performed (Figure 19-28).

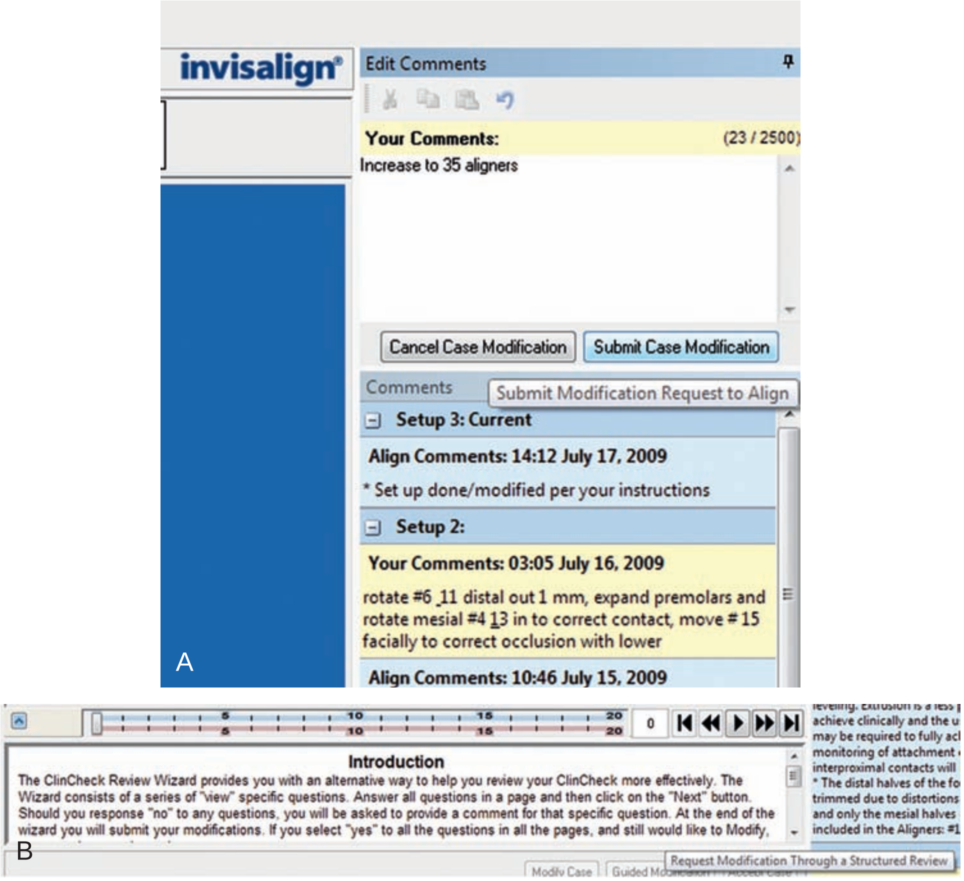
On the right side of the screen is the comments section. Comments are displayed in two colors: one designating the comments entered by the orthodontist and the other designating comments entered by the TREAT technician. The comments are displayed as the default setting although the orthodontist can click the thumb tack icon at the top of the bar on the right to view the virtual setup in a larger mode and hide the comments. Having the comments viewed at the same time as the virtual model is very helpful in enhancing communication between the orthodontist and the technician (Figure 19-29).

The last section is in the lower right of the screen. This is the tab to either modify or accept the setup. When modifying the setup, first comments are added and then they are submitted. This allows the orthodontist to add comments at different sessions (Figure 19-30, *A*). Another option is to use the guided modification system where the software presents a series of questions to prompt the user for medications (Figure 19-30, *B*). The comments can all be submitted all at one time (Figure 19-31). When accepting the setup, there is a confirmation screen intended to avoid accepting a setup by mistakenly clicking the wrong button (Figure 19-32).

ClinCheck is a powerful tool for therapeutic diagnostics. It allows the orthodontist to view treatment in every aspect from beginning to end and to plan for problems before they occur. However, it is only as powerful as the user makes it, so the more comfortable and familiar one is with the interface, the more likely one is to use it to its full potential.

INTERPROXIMAL REDUCTION AND ALIGNER TREATMENT

Early in the development of the Invisalign technique, there was a perception that most patients treated with aligners required IPR. That was because most ClinChecks that were returned to the orthodontist had significant amounts of IPR recommended by Align Technology setup technicians. There were two basic reasons for such recommendations. The first reason was



Your Comments: (23 / 2500)

Increase to 35 aligners

Setup 3: Current

Align Comments: 14:12 July 17, 2009

* Set up done/modified per your instructions

Setup 2:

Your Comments: 03:05 July 16, 2009

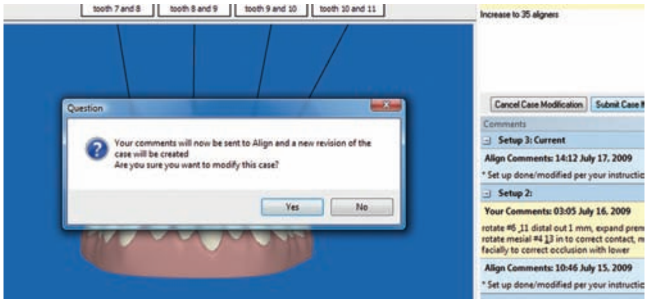
rotate #6 _11 distal out 1 mm, expand premolars and rotate mesial #4 13 in to correct contact, move # 15 facially to correct occlusion with lower

Align Comments: 10:46 July 15, 2009

Introduction

The ClinCheck Review Wizard provides you with an alternative way to help you review your ClinCheck more effectively. The Wizard consists of a series of "view" specific questions. Answer all questions in a page and then click on the "Next" button. Should you response "no" to any questions, you will be asked to provide a comment for that specific question. At the end of the wizard you will submit your modifications. If you select "yes" to all the questions in all the pages, and still would like to Modify,

FIGURE 19-30 **A,** Modification comments. **B,** Guided modification.



Your comments will now be sent to Align and a new revision of the case will be created
Are you sure you want to modify this case?

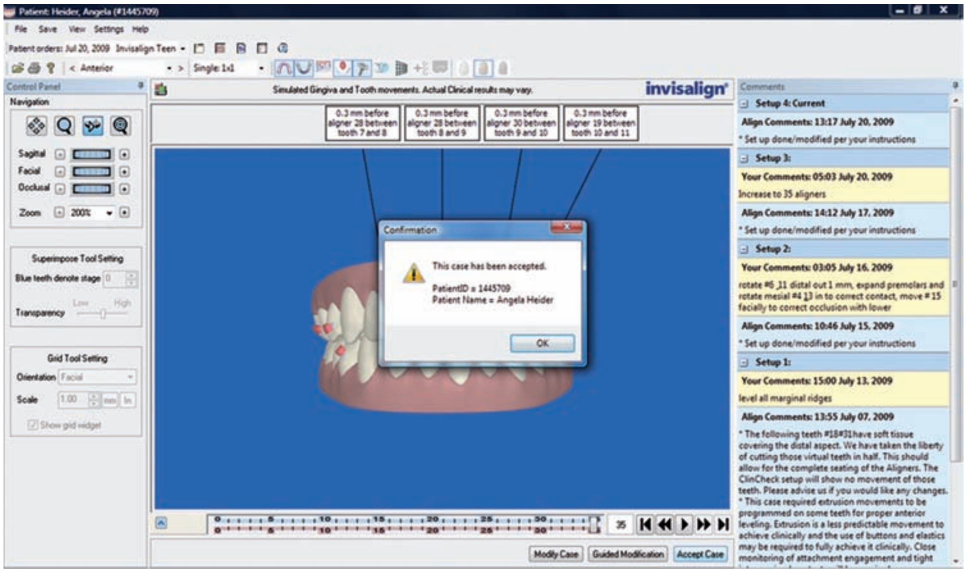
Increase to 35 aligners

FIGURE 19-31 Comments submitted (*note:* click on the "yes" tab to modify).

that many patients treated with Invisalign were patients who had undergone orthodontic relapse and thus had minor lower anterior crowding. The technicians were taught that in doing a setup they should never expand lower canines and never flare lower incisors anteriorly. That only left them one alternative, and that was to reduce tooth mass, either by IPR or extraction of a single lower incisor. The second reason was to avoid the side effect of virtual collisions. Virtual collisions occur whenever the setup technician attempts to move teeth in such a manner that one interproximal surface virtually passes through the adjacent tooth's interproximal surface, which is impossible in the physical world (Figure 19-33).

To allow the intended tooth movement to take place, the setup technician would request that the orthodontist remove the amount of tooth structure that was involved in the virtual collision. The table below is the collision table that the TREAT technician has access to in the software staging editor. The numbers across the top represent different teeth and the vertical axis represents aligner number. One can see that the virtual collisions can increase and decrease over the course of treatment. Furthermore, the collisions are measured in hundredths of a millimeter and then rounded off to tenths of a millimeter, and the interproximal surface of the tooth is mathematically interpolated by boundary recognition software. The result is that these recommendations are rounded off approximations of an estimated surface, so there is some inherent error built into the recommendation (Figure 19-34).

Additionally, any collision less than 0.05 mm is considered insignificant in that the aligner can theoretically stretch that much and not cause any problems with treatment. The result is that if there are many so-called insignificant collisions, the result may not be insignificant clinically because the tooth mass will be greater than the space allowed for in the aligner. Some teeth will be forced



Patient: Heider, Angela (#1445709)
File Save View Settings Help
Patient orders: Jul 20, 2009 Invisalign Teen
< Anterior >
Single: 1x1
Control Panel
Navigation
Sagittal
Facial
Occlusal
Zoom 200%
Superimpose Tool Setting
Blue teeth denote stage 0
Transparency Low High
Grid Tool Setting
Orientation Facial
Scale 1.00 mm In
Show grid widget
Simulated Gingiva and Tooth movements. Actual Clinical results may vary.
invisalign
0.3 mm before aligner 28 between tooth 7 and 8
0.3 mm before aligner 28 between tooth 8 and 9
0.3 mm before aligner 30 between tooth 9 and 10
0.3 mm before aligner 19 between tooth 10 and 11
Confirmation
OK
35
Modify Case
Guided Modification
Accept Case
Comments

This case has been accepted.

PatientID = 1445709
Patient Name = Angela Heider

Setup 4: Current

Align Comments: 13:17 July 20, 2009

* Set up done/modified per your instructions

Setup 3:

Your Comments: 05:03 July 20, 2009

Increase to 35 aligners

Align Comments: 14:12 July 17, 2009

* Set up done/modified per your instructions

Setup 2:

Your Comments: 03:05 July 16, 2009

rotate #6 11 distal out 1 mm, expand premolars and rotate mesial #4 13 in to correct contact, move # 15 facially to correct occlusion with lower

Align Comments: 10:46 July 15, 2009

* Set up done/modified per your instructions

Setup 1:

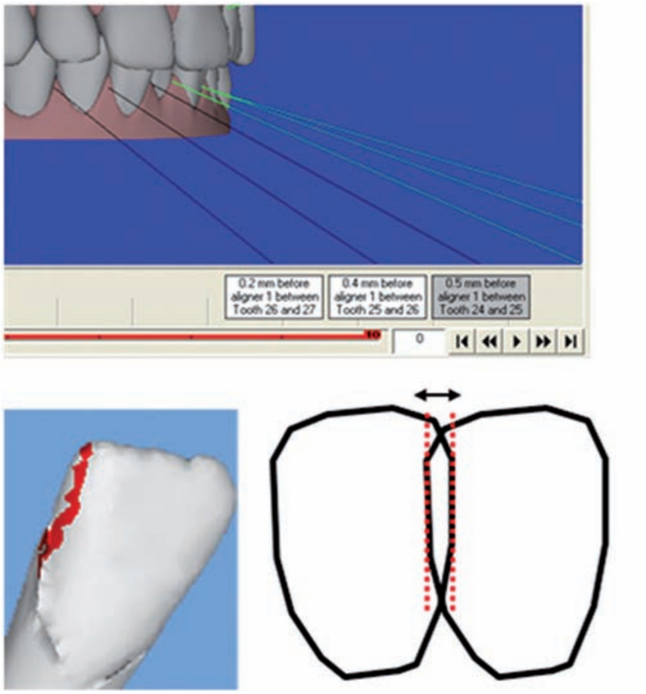
Your Comments: 15:00 July 13, 2009

level all marginal ridges

Align Comments: 13:55 July 07, 2009

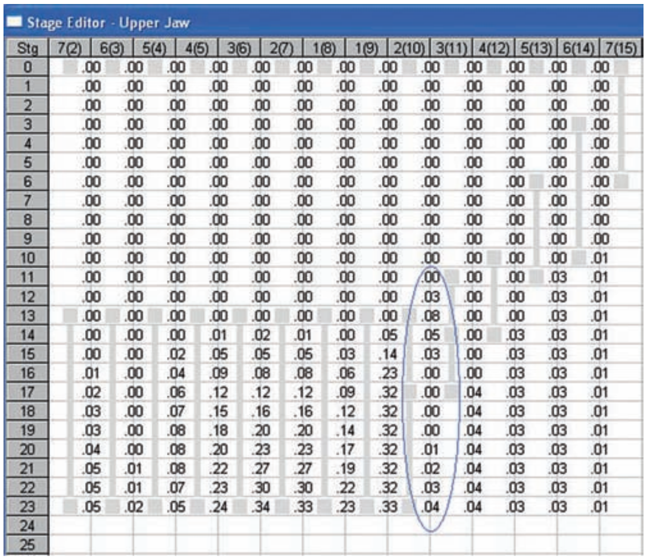
* The following teeth #18#31have soft tissue covering the distal aspect. We have taken the liberty of cutting those virtual teeth in half. This should allow for the complete seating of the Aligners. The ClinCheck setup will show no movement of those teeth. Please advise us if you would like any changes.
* This case required extrusion movements to be programmed on some teeth for proper anterior leveling. Extrusion is a less predictable movement to achieve clinically and the use of buttons and elastics may be required to fully achieve it clinically. Close monitoring of attachment engagement and tight

FIGURE 19-32 Case acceptance verification.



0.2 mm before aligner 1 between Tooth 26 and 27
0.4 mm before aligner 1 between Tooth 25 and 26
0.5 mm before aligner 1 between Tooth 24 and 25
10
0

FIGURE 19-33 Interproximal reduction recommendations based on virtual collisions.



Stage Editor - Upper Jaw

Stg	7(2)	6(3)	5(4)	4(5)	3(6)	2(7)	1(8)	1(9)	2(10)	3(11)	4(12)	5(13)	6(14)	7(15)
0	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	
1	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	
2	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	
3	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	
4	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	
5	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	
6	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	
7	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	
8	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	
9	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	
10	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.01	
11	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.03	.01	
12	.00	.00	.00	.00	.00	.00	.00	.00	.03	.00	.00	.03	.01	
13	.00	.00	.00	.00	.00	.00	.00	.00	.08	.00	.00	.03	.01	
14	.00	.00	.00	.01	.02	.01	.00	.05	.05	.00	.03	.03	.01	
15	.00	.00	.02	.05	.05	.05	.03	.14	.03	.00	.03	.03	.01	
16	.01	.00	.04	.09	.08	.08	.06	.23	.00	.00	.03	.03	.01	
17	.02	.00	.06	.12	.12	.12	.09	.32	.00	.04	.03	.03	.01	
18	.03	.00	.07	.15	.16	.16	.12	.32	.00	.04	.03	.03	.01	
19	.03	.00	.08	.18	.20	.20	.14	.32	.00	.04	.03	.03	.01	
20	.04	.00	.08	.20	.23	.23	.17	.32	.01	.04	.03	.03	.01	
21	.05	.01	.08	.22	.27	.27	.19	.32	.02	.04	.03	.03	.01	
22	.05	.01	.07	.23	.30	.30	.22	.32	.03	.04	.03	.03	.01	
23	.05	.02	.05	.24	.34	.33	.23	.33	.04	.04	.03	.03	.01	
24														
25														

FIGURE 19-34 Virtual collision table in stage editor.

to intrude to reduce arch length; this is often the terminal molar but it could be any tooth in either arch (Figure 19-35).

Understanding this process allows the orthodontist to control the treatment better. This becomes very important because the orthodontist is given three IPR options on the treatment prescription form: *PRIMARILY*, *IF NEEDED*, and *NONE*. The *IF NEEDED* option does not necessarily mean in the best interests of the patient but rather subjugates the responsibility for any decision regarding IPR to the technician and therefore should only be selected if the orthodontist is prepared to give specific instructions about under what conditions IPR can be used. If the orthodontist is unsure about whether to use IPR, he or she may request no IPR on the prescription form. In order to ensure there are no insignificant collisions, one may also request NO COLLISIONS in the setup to mimic treatment performed with fixed appliances. It is also important to understand there is an equal likelihood of insignificant spacing that may result in residual spaces when treatment is completed.

Staging

An important aspect of controlling tooth movement with aligners is staging. *Staging* is the sequence in which and speed at which teeth are moved with aligners. Figure

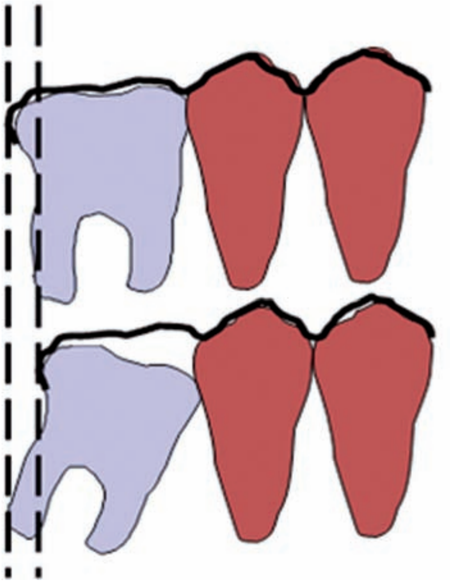


FIGURE 19-35 Aligner size tooth mass discrepancy.

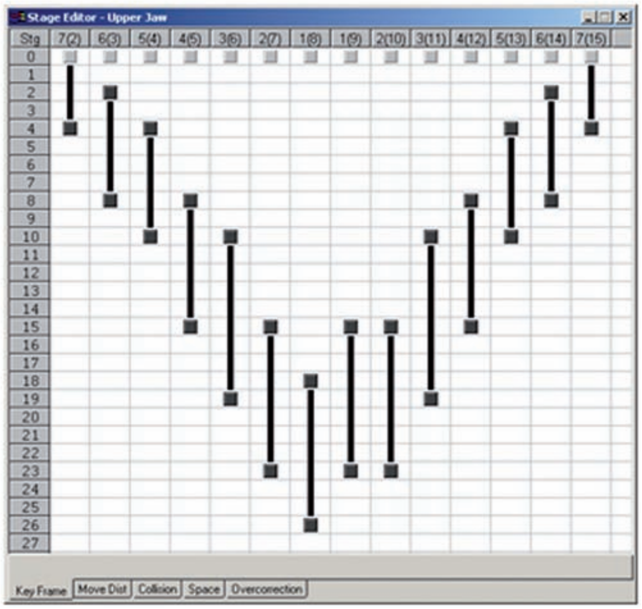


FIGURE 19-36 Segmented staging diagram.

19-36 represents a classic staging diagram. As in the collision table, the numbers across the top represent different teeth and the vertical axis represents aligner number. The difference is that the staging diagram is available to the orthodontist in ClinCheck. The vertical black bars in the diagram indicate the timing and rate of tooth movement. Each aligner number then represents one stage. You will notice one shortcoming of the staging diagram is that there is no illustration of the rate of tooth movement. In other words it simply informs the orthodontist of whether the tooth is being moved. The orthodontist must then interpolate the rate of movement by estimating the total distance and dividing by the number of aligners, assuming equal rates of movement occur throughout the entire distance moved. In addition, there is no way for the orthodontist to know whether the movement represents linear movement or rotational movement. One only knows that the tooth is moving. The original default staging plans involved segmented tooth movements, as illustrated in Figure 19-36. The thought process was based on the classic notion of anchorage where one group of teeth is held stationary while a smaller group of teeth are moved. Difficult movements were often left to the end of treatment and resulted in prolonging treatment time by adding multiple additional stages. In order to reduce excessive numbers of additional stages, some difficult movements were accelerated beyond a reasonable rate of movement. It sometimes became a self-fulfilling prophesy that difficult movements were unsuccessful with aligners. In addition, teeth that were supposedly to be held in place as an anchorage unit moved in the same manner that anchorage units move with fixed appliances.

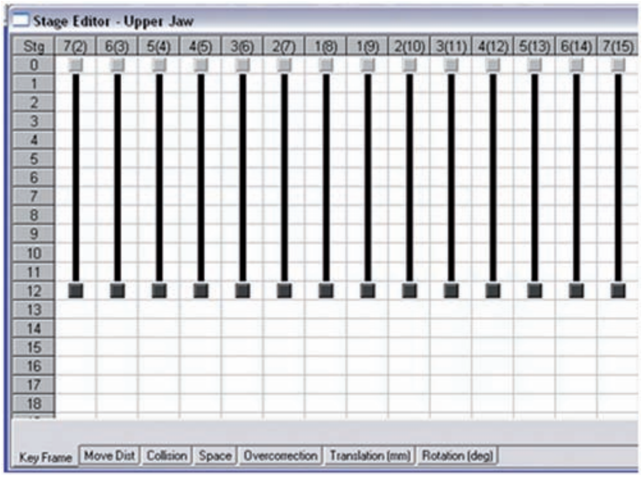


FIGURE 19-37 Simultaneous staging diagram.

An alternative to segmented staging that mimics fixed appliance treatment more closely is simultaneous staging. First suggested by Foy in 2004[6a] (Michael Foy, personal communication, Invisalign Alpha Group meeting, 2004, Salt Lake City, UT, 2004) and then refined by this author (Staging Strategies, Effectiveness and Efficiency with Invisalign Treatment, 2005 Invisalign Summit, Las Vegas, NV) and then after several years the simultaneous movement concept was adopted by Align Technology in 2007 (Figure 19-37). The basis for simultaneous movement is that all the teeth within each arch are moved together from the initial stage through the final stage.

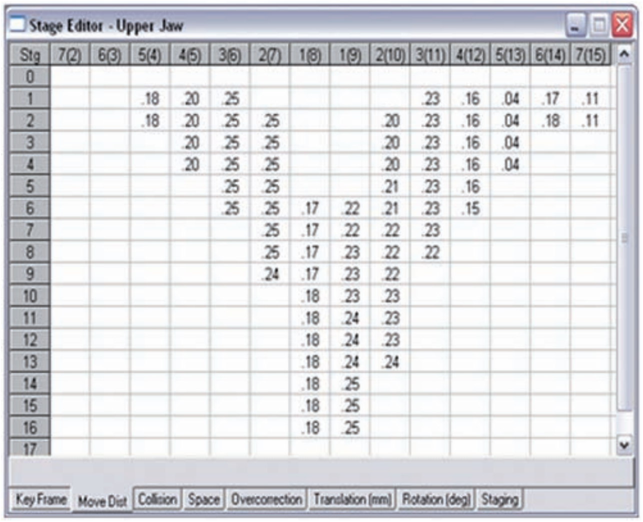
The tooth that moves the most dictates the overall number of stages based on the maximum allowable tooth velocity. Moving the other teeth simultaneously from the first to the last stage reduces the velocity for all the other movements and increases their predictability without increasing the overall number of aligners. We will examine this in more detail with a series of screen captures from the TREAT software that provides the actual measures of intended velocities of tooth movement (Figures 19-38 to 19-42). If you examine Figure 19-38, you will notice that all the anterior teeth are moving at maximum velocity (0.25 mm per stage).

In Figure 19-39, it was determined that the upper left lateral was the rate limiting tooth and when these movements were started from the beginning of treatment along with all the other teeth, the result was a decrease from 16 stages to 12 stages and all the teeth except the rate limiting tooth are actually moving slower at each stage than they were previously.

There are times when the linear velocity is not the rate limiting step, but rather it is the rotational velocity (Figures 19-39 and 19-40). In Figure 19-40 one can see that even though the linear movements were under the maximum velocity, the rotational velocity was greater than desirable. In order to increase the predictability of treatment, rotational velocity should be kept under 2 degrees per stage (Figure 19-41). You can see that when the rotational velocity is reduced to an acceptable limit, the number of stages once again increases to 19 stages.

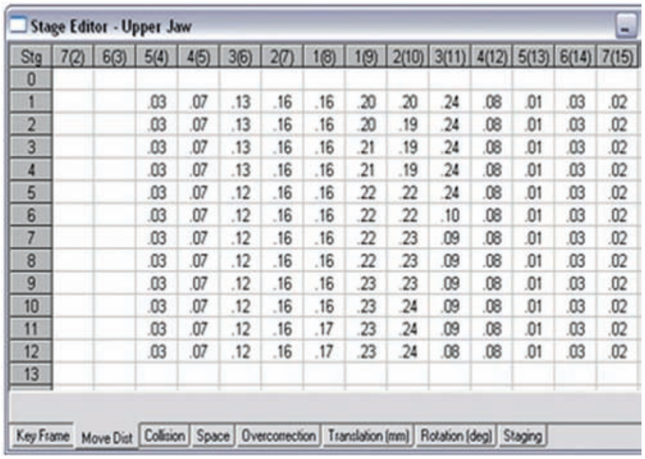
The side effect of reducing the rotational velocity is to further reduce the linear velocity at the same time. Note the reduction of the velocity of linear movement of the upper left lateral from 0.24 mm per stage to 0.15 mm per stage (see Figures 19-38 to 19-42), and although it may increase the number of stages slightly, the predictability of treatment outcomes is greatly improved.

It is important to understand that although significant amounts of clinical testing have gone into the development of staging patterns, the orthodontist can always request custom staging when he or she feels it is necessary to improve treatment outcomes. Although not recommended by Align Technology, there are some orthodontists who, for complex movements, greatly reduce the amount of linear movement per stage to about 0.1 mm per stage and then deliver fresh aligners on a weekly basis in order to have the aligners maintain greater aligner rigidity. Although this results in twice as many aligners, the total treatment time remains the same.



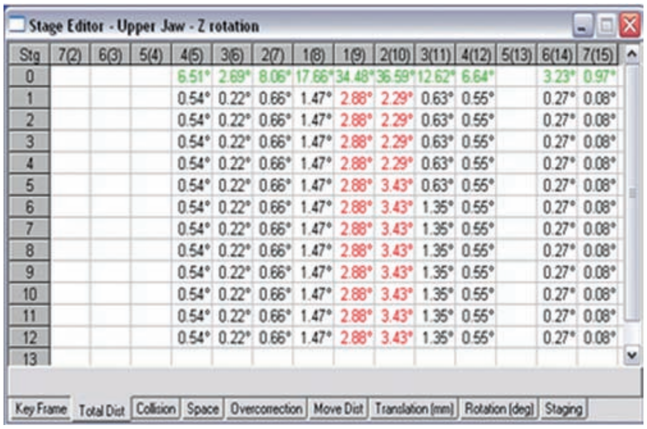
Stg	7(2)	6(3)	5(4)	4(5)	3(6)	2(7)	1(8)	1(9)	2(10)	3(11)	4(12)	5(13)	6(14)	7(15)
0														
1			.18	.20	.25					.23	.16	.04	.17	.11
2			.18	.20	.25	.25			.20	.23	.16	.04	.18	.11
3				.20	.25	.25			.20	.23	.16	.04		
4				.20	.25	.25			.20	.23	.16	.04		
5					.25	.25			.21	.23	.16			
6					.25	.25	.17	.22	.21	.23	.15			
7						.25	.17	.22	.22	.23				
8						.25	.17	.23	.22	.22				
9						.24	.17	.23	.22					
10							.18	.23	.23					
11							.18	.24	.23					
12							.18	.24	.23					
13							.18	.24	.24					
14							.18	.25						
15							.18	.25						
16							.18	.25						
17														

FIGURE 19-38 Segmented staging diagram linear movement.



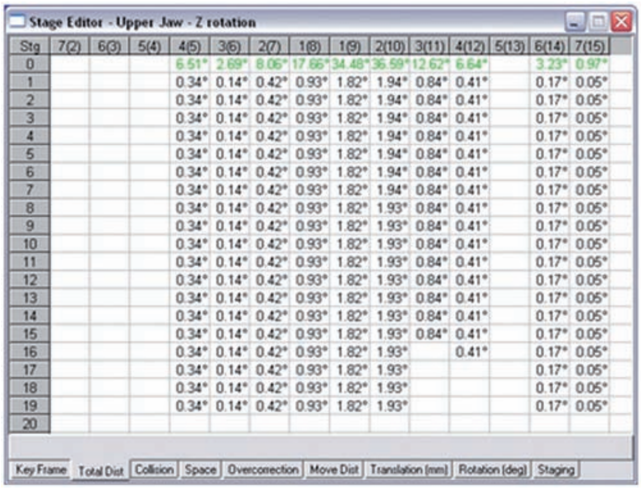
Stg	7(2)	6(3)	5(4)	4(5)	3(6)	2(7)	1(8)	1(9)	2(10)	3(11)	4(12)	5(13)	6(14)	7(15)
0														
1			.03	.07	.13	.16	.16	.20	.20	.24	.08	.01	.03	.02
2			.03	.07	.13	.16	.16	.20	.19	.24	.08	.01	.03	.02
3			.03	.07	.13	.16	.16	.21	.19	.24	.08	.01	.03	.02
4			.03	.07	.13	.16	.16	.21	.19	.24	.08	.01	.03	.02
5			.03	.07	.12	.16	.16	.22	.22	.24	.08	.01	.03	.02
6			.03	.07	.12	.16	.16	.22	.22	.10	.08	.01	.03	.02
7			.03	.07	.12	.16	.16	.22	.23	.09	.08	.01	.03	.02
8			.03	.07	.12	.16	.16	.22	.23	.09	.08	.01	.03	.02
9			.03	.07	.12	.16	.16	.23	.23	.09	.08	.01	.03	.02
10			.03	.07	.12	.16	.16	.23	.24	.09	.08	.01	.03	.02
11			.03	.07	.12	.16	.17	.23	.24	.09	.08	.01	.03	.02
12			.03	.07	.12	.16	.17	.23	.24	.08	.08	.01	.03	.02
13														

FIGURE 19-39 Simultaneous staging diagram linear movement.



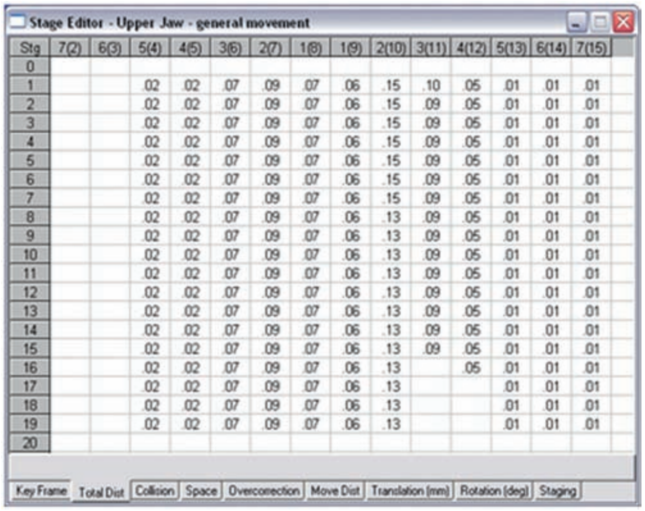
Stg	7(2)	6(3)	5(4)	4(5)	3(6)	2(7)	1(8)	1(9)	2(10)	3(11)	4(12)	5(13)	6(14)	7(15)
0				6.51°	2.69°	8.06°	17.66°	34.48°	36.59°	12.62°	6.64°		3.23°	0.97°
1				0.54°	0.22°	0.66°	1.47°	2.88°	2.29°	0.63°	0.55°		0.27°	0.08°
2				0.54°	0.22°	0.66°	1.47°	2.88°	2.29°	0.63°	0.55°		0.27°	0.08°
3				0.54°	0.22°	0.66°	1.47°	2.88°	2.29°	0.63°	0.55°		0.27°	0.08°
4				0.54°	0.22°	0.66°	1.47°	2.88°	2.29°	0.63°	0.55°		0.27°	0.08°
5				0.54°	0.22°	0.66°	1.47°	2.88°	3.43°	0.63°	0.55°		0.27°	0.08°
6				0.54°	0.22°	0.66°	1.47°	2.88°	3.43°	1.35°	0.55°		0.27°	0.08°
7				0.54°	0.22°	0.66°	1.47°	2.88°	3.43°	1.35°	0.55°		0.27°	0.08°
8				0.54°	0.22°	0.66°	1.47°	2.88°	3.43°	1.35°	0.55°		0.27°	0.08°
9				0.54°	0.22°	0.66°	1.47°	2.88°	3.43°	1.35°	0.55°		0.27°	0.08°
10				0.54°	0.22°	0.66°	1.47°	2.88°	3.43°	1.35°	0.55°		0.27°	0.08°
11				0.54°	0.22°	0.66°	1.47°	2.88°	3.43°	1.35°	0.55°		0.27°	0.08°
12				0.54°	0.22°	0.66°	1.47°	2.88°	3.43°	1.35°	0.55°		0.27°	0.08°
13														

FIGURE 19-40 Simultaneous staging diagram rotational movement.



Stg	7(2)	6(3)	5(4)	4(5)	3(6)	2(7)	1(8)	1(9)	2(10)	3(11)	4(12)	5(13)	6(14)	7(15)
0				6.51°	2.69°	8.06°	17.66°	34.48°	36.59°	12.62°	6.64°		3.23°	0.97°
1				0.34°	0.14°	0.42°	0.93°	1.82°	1.94°	0.84°	0.41°		0.17°	0.05°
2				0.34°	0.14°	0.42°	0.93°	1.82°	1.94°	0.84°	0.41°		0.17°	0.05°
3				0.34°	0.14°	0.42°	0.93°	1.82°	1.94°	0.84°	0.41°		0.17°	0.05°
4				0.34°	0.14°	0.42°	0.93°	1.82°	1.94°	0.84°	0.41°		0.17°	0.05°
5				0.34°	0.14°	0.42°	0.93°	1.82°	1.94°	0.84°	0.41°		0.17°	0.05°
6				0.34°	0.14°	0.42°	0.93°	1.82°	1.94°	0.84°	0.41°		0.17°	0.05°
7				0.34°	0.14°	0.42°	0.93°	1.82°	1.94°	0.84°	0.41°		0.17°	0.05°
8				0.34°	0.14°	0.42°	0.93°	1.82°	1.93°	0.84°	0.41°		0.17°	0.05°
9				0.34°	0.14°	0.42°	0.93°	1.82°	1.93°	0.84°	0.41°		0.17°	0.05°
10				0.34°	0.14°	0.42°	0.93°	1.82°	1.93°	0.84°	0.41°		0.17°	0.05°
11				0.34°	0.14°	0.42°	0.93°	1.82°	1.93°	0.84°	0.41°		0.17°	0.05°
12				0.34°	0.14°	0.42°	0.93°	1.82°	1.93°	0.84°	0.41°		0.17°	0.05°
13				0.34°	0.14°	0.42°	0.93°	1.82°	1.93°	0.84°	0.41°		0.17°	0.05°
14				0.34°	0.14°	0.42°	0.93°	1.82°	1.93°	0.84°	0.41°		0.17°	0.05°
15				0.34°	0.14°	0.42°	0.93°	1.82°	1.93°	0.84°	0.41°		0.17°	0.05°
16				0.34°	0.14°	0.42°	0.93°	1.82°	1.93°		0.41°		0.17°	0.05°
17				0.34°	0.14°	0.42°	0.93°	1.82°	1.93°				0.17°	0.05°
18				0.34°	0.14°	0.42°	0.93°	1.82°	1.93°				0.17°	0.05°
19				0.34°	0.14°	0.42°	0.93°	1.82°	1.93°				0.17°	0.05°
20														

FIGURE 19-41 Simultaneous staging diagram reduced rate of rotational movement.



Stg	7(2)	6(3)	5(4)	4(5)	3(6)	2(7)	1(8)	1(9)	2(10)	3(11)	4(12)	5(13)	6(14)	7(15)
0														
1			.02	.02	.07	.09	.07	.06	.15	.10	.05	.01	.01	.01
2			.02	.02	.07	.09	.07	.06	.15	.09	.05	.01	.01	.01
3			.02	.02	.07	.09	.07	.06	.15	.09	.05	.01	.01	.01
4			.02	.02	.07	.09	.07	.06	.15	.09	.05	.01	.01	.01
5			.02	.02	.07	.09	.07	.06	.15	.09	.05	.01	.01	.01
6			.02	.02	.07	.09	.07	.06	.15	.09	.05	.01	.01	.01
7			.02	.02	.07	.09	.07	.06	.15	.09	.05	.01	.01	.01
8			.02	.02	.07	.09	.07	.06	.13	.09	.05	.01	.01	.01
9			.02	.02	.07	.09	.07	.06	.13	.09	.05	.01	.01	.01
10			.02	.02	.07	.09	.07	.06	.13	.09	.05	.01	.01	.01
11			.02	.02	.07	.09	.07	.06	.13	.09	.05	.01	.01	.01
12			.02	.02	.07	.09	.07	.06	.13	.09	.05	.01	.01	.01
13			.02	.02	.07	.09	.07	.06	.13	.09	.05	.01	.01	.01
14			.02	.02	.07	.09	.07	.06	.13	.09	.05	.01	.01	.01
15			.02	.02	.07	.09	.07	.06	.13	.09	.05	.01	.01	.01
16			.02	.02	.07	.09	.07	.06	.13		.05	.01	.01	.01
17			.02	.02	.07	.09	.07	.06	.13			.01	.01	.01
18			.02	.02	.07	.09	.07	.06	.13			.01	.01	.01
19			.02	.02	.07	.09	.07	.06	.13			.01	.01	.01
20														

FIGURE 19-42 Segmented staging diagram reduced rate of linear movement.

BIOMECHANICS OF ALIGNER TREATMENT

Control of root position and anchorage is often the greatest challenge faced by any orthodontist. The question then becomes: Is treatment with Invisalign a practical alternative to fixed appliances? Several authors have examined outcomes of Invisalign treatment. Patel et al.[7] found significant improvement in the PAR index in patients treated with Invisalign. Vincent[8] found improvements in the ABO objective grading system with tooth alignment but not in posterior occlusal contacts. Djeu et al.[9] compared Invisalign to fixed appliances and found the ABO objective grading system (OGS) scores were improved more for the fixed appliance group than for the aligner group, whereas Brown et al.[10] reported that overall, Invisalign was found to be more effective than fixed appliances at producing the outcome defined by the OGS. In a systematic review in 2005, Lagravere and Flores-Mir[11] found the literature lacking and concluded that "Clinicians will have to rely on their Invisalign clinical experience, the opinions of experts and the limited published evidence when using Invisalign appliances." It is hoped that after the following section on biomechanics and Invisalign, the reader will be better equipped to make sound clinical decisions and have a greater understanding of the strengths and weaknesses of aligners.

One question to keep in mind during this entire discussion of biomechanics is: If teeth were capable of cognition, would they know what was applying the force? In 1999, Sims[12] predicted the future of orthodontics would include the abolition of bracket systems. In his 1986 textbook *Contemporary Orthodontics,*[13] Proffit stated that "adult patients traditionally have been somewhat reluctant to wear obvious fixed appliances and frequently indicate their preference for a removable appliance." He also described the characteristics required of an orthodontic appliance system. "No matter what the type of orthodontic appliance, it must meet certain basic design criteria: it (1) should not interfere with function; (2) should cause no harm to the oral tissues or interfere with the maintenance of good oral hygiene; (3) should be as light and inconspicuous as possible, yet sufficiently strong to withstand masticatory forces and a reasonable amount of abuse; (4) must be firmly retained in position; (5) must be capable of exerting an appropriately controlled force in the correct direction and delivering this force for as long as possible between adjustment visits; and (6) should allow control of anchorage so that tooth movements other than those intended are minimized." On the surface, it would appear that Invisalign satisfies all these criteria.

According to Proffit,[13] "removable appliances by their very nature produce simple tipping movements of teeth, making control of tooth position extremely difficult" and "as a practical matter, it can be difficult to maintain removable appliances in place against the displacing effects" of the forces required to produce controlled root movement. He concluded that the usual solution to this problem was to use fixed appliances. When describing the experiences with Invisalign at University of the Pacific, Dugoni[14] wrote in 2002, "We then went on to patients in whom the mandibular incisors would have to be extracted to determine whether we could close those spaces in a parallel manner. This involved changes not only in the material but also in the technique. Ultimately, we were able to move the teeth bodily. Experimentation has continued with extraction cases to determine whether we could bodily move canines into first premolar positions after extractions." His conclusion was that

> *"the use of the Aligners is far more complicated than most people believe. It takes a knowledgeable clinician with considerable experience to use the appliance to its maximum. What that maximum is, I do not know."*

In order to determine just what that maximum might be with Invisalign in its current rendition of aligner materials, we must examine the biomechanics of tooth movement with Invisalign.

Simple versus Difficult Movements

To examine the biomechanics of tooth movement with aligners, first how aligners move teeth will be described. With a typical fixed appliance, the wire is engaged in a bracket with the adhesive retaining the bracket on the tooth. The active archwire is elastically deformed and moves the tooth to a determined position as it returns to its original shape. With an aligner, the plastic encapsulates the tooth and in doing so must provide both retention and activation to move the teeth. In general the natural undercuts of the teeth provide the retention and the active component to move teeth by the elastic deformation of the aligner. This is important for two reasons: first, the aligner elastic deformation cannot be so great as to overcome the retention forces; and second, there are certain directions in which aligner has a greater inherent ability to undergo elastic deformation. For instance, a faciolingual movement is fairly predictable because the entire body of the aligner can be distorted elastically and then returns to its original shape carrying the tooth with it. The total desired movement is then subdivided in such a way that the aligners remain within this range of elastic deformation and a sequence of aligners is made to accomplish the entire desired movement. The number of aligners or stages then is based on the distance the tooth must be moved. In contrast a vertical movement would require the aligner to essentially stretch within the matrix of the plastic and at the same time maintain retention of the tooth it was attempting to move. Because there is very limited ability for such elasticity within the plastic itself, these movements must be divided into very small increments and are considered difficult. Given this understanding of the basic nature of how aligners move teeth, it is not surprising that there are multiple movements that are considered unpredictable with aligners. Some of these difficult movements include controlling torque, root parallelism, rotations and extrusions. These issues will be discussed within the context of traditional orthodontic biomechanics, specifically how aligners deal with forces and moments. The purpose of this chapter is not a detailed review of orthodontic biomechanics, but rather how aligners relate to these concepts. It should be noted that the basis of these discussions is the proprietary plastic used to make aligners known as Exceed 30 (Align Technology, Inc.), a 0.030-inch (0.76-mm)-thick thermoforming plastic. There is ongoing research using dual-layer and other materials to provide aligners with different biomechanical properties, but these materials will not be discussed here.

One can see in Table 19-1 that over the course of the past 20 years, the levels of force thought to be required to perform different movements has steadily decreased.

Continuing with that trend, recent studies have suggested that given time, even forces as low as 18 *g* are sufficient to produce bodily movement.[16] Because the force delivered with an aligner made from Exceed 30 is 200 *g* initially and decays to essentially a constant level of 40 *g* within around 48 hours, there should be no problem delivering adequate forces to the teeth to create desired movements. Controlling those forces then becomes the issue.

How the force is delivered and the reaction of the tooth to that force are functions of multiple factors. These include the center of rotation, the center of resistance, and the point at which the force is applied.

The goal is to control root position during movement to achieve the desired end results with the minimum amount of complexity. Controlling the moment-to-force ratio can do this. Classic orthodontic biomechanics has described the effects of changing the moment-to-force ratio as illustrated in Figure 19-43, adapted from Proffit.[15]

TABLE 19-1 **Optimal Forces for Orthodontic Movement Adapted from Proffit[13,15]**

	1986	2000
Type of Movement	**Force (*g*)**	
Tipping	50 to 75	35 to 60
Bodily movement (translation)	100 to 150	70 to 120
Root uprighting	75 to 125	50 to 100
Rotation	50 to 100	35 to 60
Extrusion	50 to 100	35 to 60
Intrusion	15 to 25	10 to 20

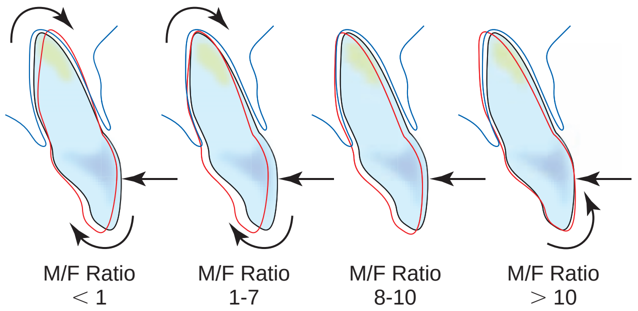


FIGURE 19-43 Effect of moment-to-force ratios.

In traditional orthodontic biomechanics, the discussions are typically centered on fixed attachments in the form of brackets with forces applied by wires, with a small moment arm and relatively high forces required to meet moment-to-force ratios.

In order to better understand the dynamics of root control with aligners, we will now examine the biomechanics of tooth movement with aligners and compare that with our understanding of movement with fixed appliances. Specifically, the design and placement of attachments and auxiliaries to accomplish controlled two-point force application are examined. In all these discussions, it is important to understand that for effective tooth movement to take place, even in simple situations, aligners must be worn 22 hours a day, essentially the same as for fixed appliances.

One of the problems that is seen when attempting incisor root movements with aligners is that the intended movement and the actual movement are sometimes different. The reason for this is exactly what Proffit described as happening with removable appliances in general—there is not enough retention to offset the force needed to generate the movement. The result is that seen in Figures 19-44 and 19-45, *A, B*.

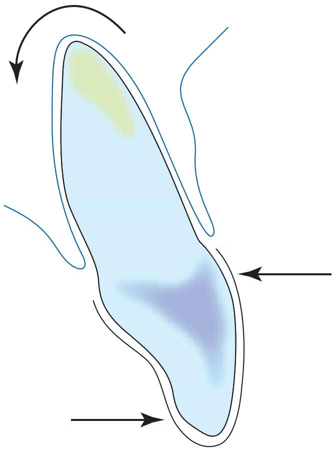


FIGURE 19-44 Theoretical moment-to-force ratio to achieve lingual root movement with an aligner.

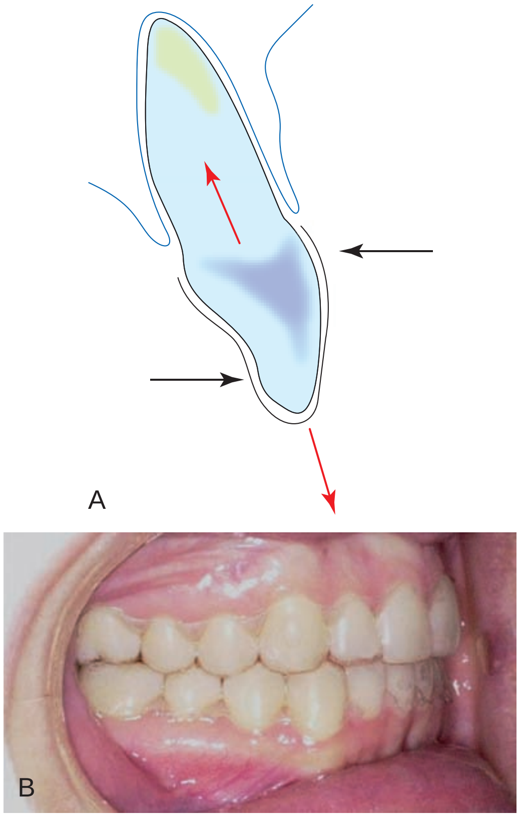


FIGURE 19-45 **A,** Clinical expression of moment-to-force ratio to achieve lingual root movement with an aligner. **B,** Clinical expression of moment-to-force ratio to achieve lingual root movement with an aligner.

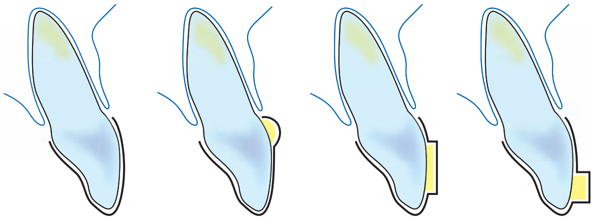


FIGURE 19-46 The evolution of attachments.

ATTACHMENTS, POWER RIDGES, AND AUXILIARIES

One solution to aligner displacement is the proper design and placement of attachments. Attachments can be used for retention of the aligner as well as to enhance or facilitate specific tooth movements. Figure 19-46 illustrates the evolution of attachments used to help eliminate this problem. The key is to provide a ledge for the aligner to grip that is perpendicular to the direction of displacement and of sufficient size to provide enough surface area to offset the force delivered. Another simple rule of thumb is to place the attachment far enough away from the gingival margin that the aligner will not spread or stretch and slip off the attachment. This is an important concept because over time the aligners tend to "relax"—that is, exert less force, so the clinically observed side effect is that the gingival third tends to become less retentive. This is in contrast to the findings of Jones et al.[17] based on laboratory results with in-office–fabricated aligners whose properties were not affected by the oral environment.

Movements that are termed "difficult movements" require a more sophisticated approach to attachment design than was used in the past. Recognizing the limitation of aligners and attachments to accomplish certain tooth movements, engineers at Align Technology initiated efforts to design a better aligner/attachment system and to do so have developed the Virtual Invisalign Laboratory, which is a sophisticated series of software tools that enable them to evaluate the expected clinical response to various attachment designs and placements. The approach, based on the principles of biomechanics, is composed of three parts: virtual modeling, in vitro testing, and clinical evaluation of the resulting designs. Using this approach, the probability of achieving the movement is greatly enhanced.

Virtual modeling is first used to test a myriad of possible solutions and identify those that produce the desired force system. These models may include changes in attachment shape as well as variations in the geometry of the aligner itself (Figure 19-47). After considering possible designs, they are then fabricated and the force systems are measured using laboratory equipment specifically designed to measure force systems from aligner/attachment combinations. Successful designs are then moved into clinical testing.

At the time of this printing, attachments to accomplish extrusion of the anterior teeth and rotations of the canines are available for clinical treatment. Each attachment is now custom designed for a specific movement on a specific tooth of each individual patient and, for the first time with this technique, it is truly patient-specific treatment. It should be noted that in addition to specific

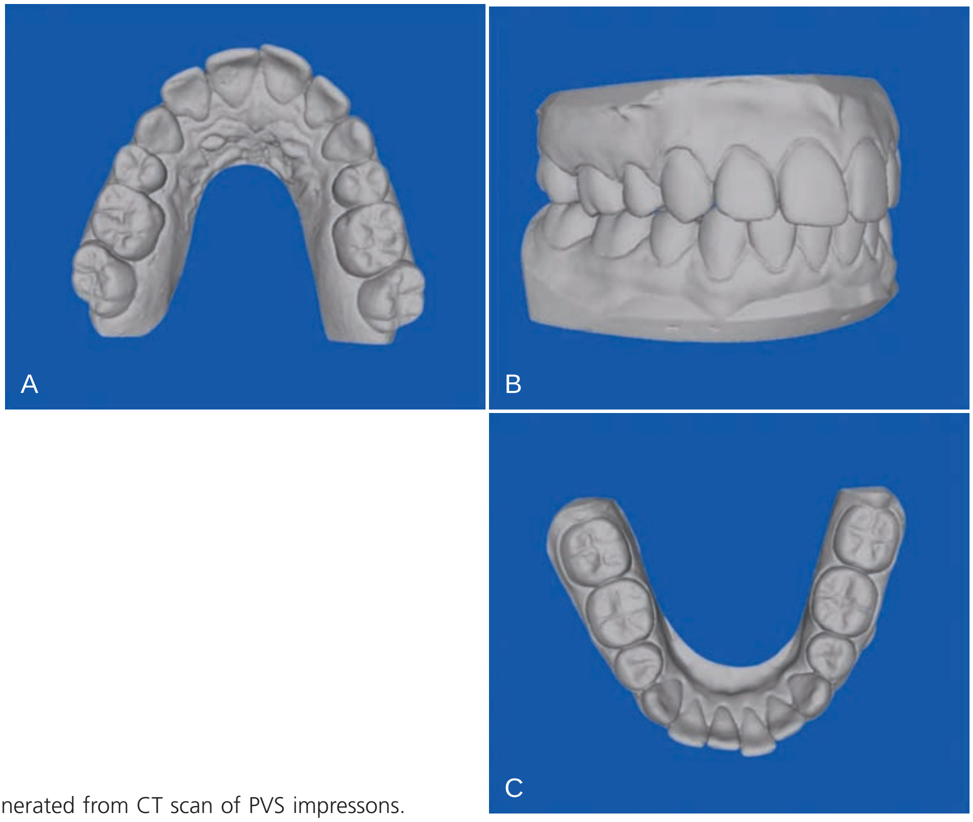


FIGURE 19-47 **A–C,** Virtual models generated from CT scan of PVS impressons.

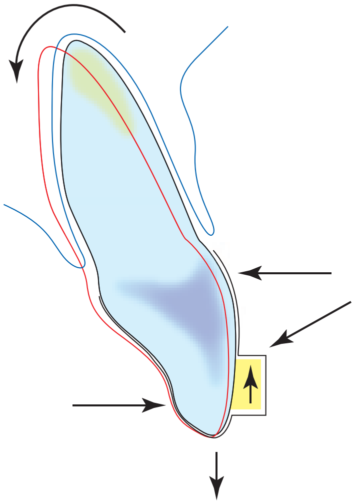


FIGURE 19-48 Horizontal rectangular attachment.

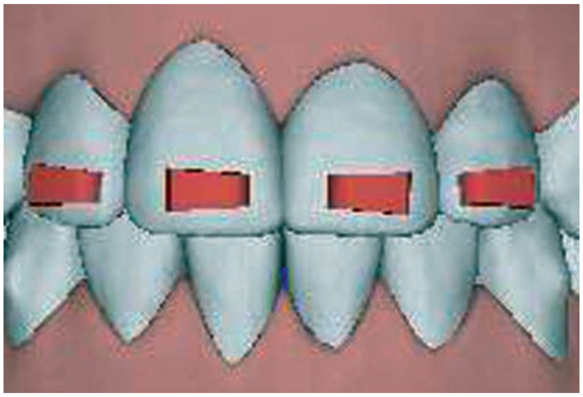


FIGURE 19-49 Horizontal rectangular attachment as viewed in ClinCheck.

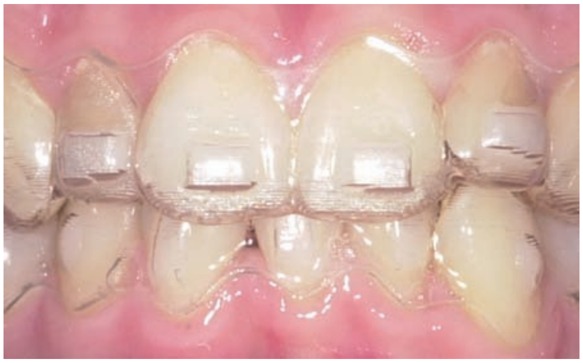


FIGURE 19-50 Horizontal rectangular attachment clinical appearance.

directions of force application, the amount of force is controlled by "preactivating" the aligner–attachment interface (see Figure 19-47). As clinical trials progress and comparisons can be made between virtual experiments and actual clinical results, the design and placement of attachments will become further refined. Until we have those results, the following review will give the reader a good understanding of the dynamics of attachment design and placement (see Figures 19-46 and 19-48 to 19-50).

Controlling Torque

A net force of 40 *g* (base level force of an aligner after 48 hours) intended to move the tooth lingually would require a moment of 320 to 400 *g*-mm (M/F ratio 8-10) for bodily movement or greater than 400 gmm (F/M ratio less than 10) for lingual root movement (Figures 19-51 and 19-52). Improper attachment design or placement allows the delivery of only 280 *g*-mm moment in conjunction with 40 *g* force, resulting in controlled lingual crown tipping (Figure 19-53). It must be kept in mind that the aligner provides the same level of force on both sides of the teeth, even though the forces may be in opposite directions. This means that in the absence of spaces to close, just as with fixed appliances, there must be some outside force system such as interarch elastics to provide a net distalizing force on the maxillary anterior teeth to produce lingual root movement.

There is an inherent problem with rectangular attachments, because it is difficult for the patient to insert and remove the aligners. If the attachment and the aligner are not completely coupled, then the result is an unwanted force system and unpredictable tooth movements (Figures 19-54 and 19-55).

In order to facilitate greater ease of insertion and removal, as well as eliminate the all-or-none situation, the beveled attachment was developed by rotating a portion of the rectangular attachment virtually into the tooth surface[22] (Figures 19-56 and 19-57).

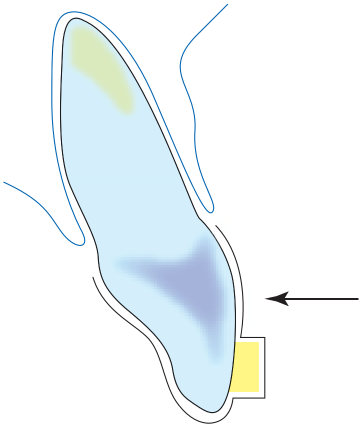


FIGURE 19-51 Force applied by aligner on facial surface.

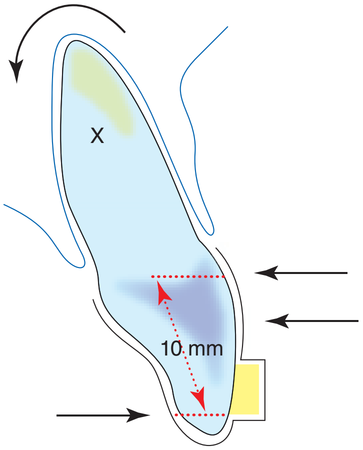


FIGURE 19-52 Force–moment diagram with attachment in incisal third of tooth.

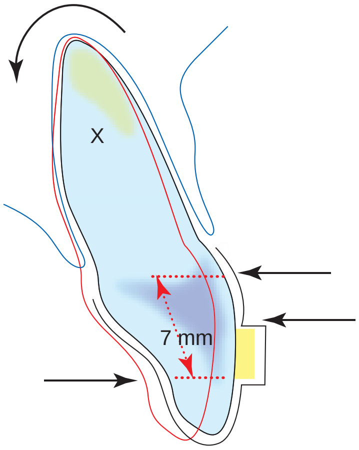


FIGURE 19-53 Force–moment diagram with attachment in middle third of tooth.

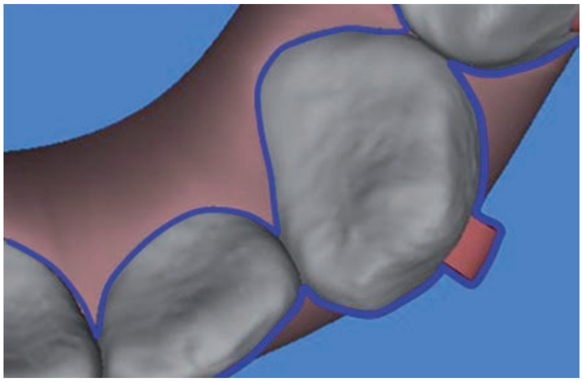


FIGURE 19-54 Aligner and rectangular attachment properly coupled.

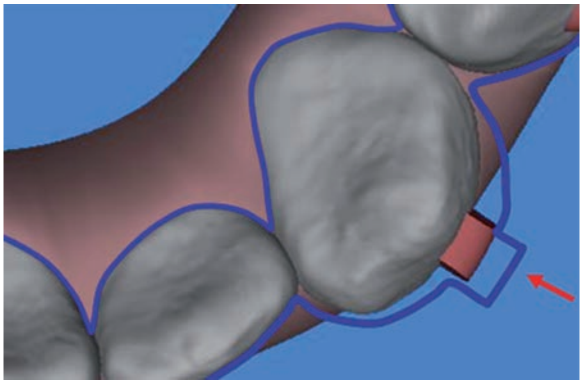


FIGURE 19-55 Aligner and rectangular attachment improperly coupled.

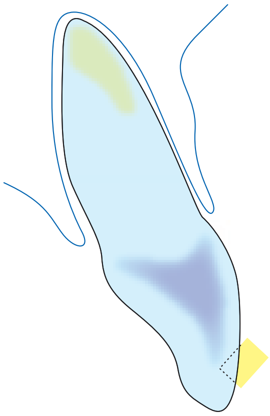


FIGURE 19-56 The beveled attachment.

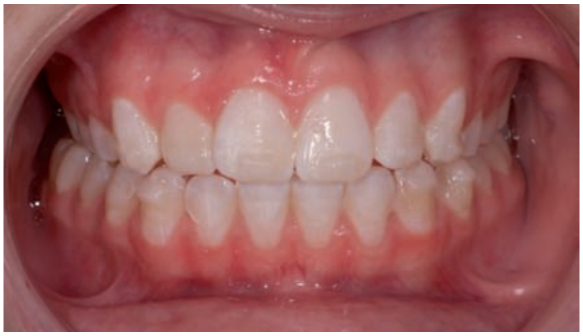


FIGURE 19-57 Clinical appearance of the beveled attachment.

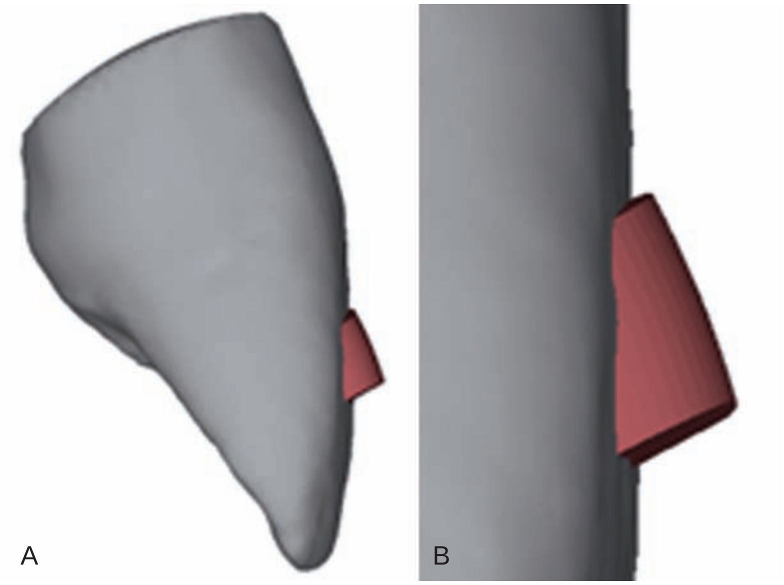


FIGURE 19-58 **A,** Gingivally beveled attachment. **B,** Gingivally beveled attachment close-up.

The beveled attachment can be utilized in multiple orientations simply by having the technician rotate the attachment in a different manner. There are theories that rotating the bevel in specific directions will enhance specific movements.[18] Research is ongoing to determine the effectiveness of such orientations. Examples are given in Figures 19-58 and 19-59.

Attachments can be used in any location that will enhance retention or movement (Figure 19-60).

An alternative to attachments that help facilitate torque control is the power ridge. Power ridges are engineered corrugations placed at specific locations to enhance the undercut near the gingival margin of teeth undergoing torquing movements. The ridges function in two ways. The first is to stiffen the gingival third of the aligner to make it more resilient. The other is to provide additional force as close to the gingival margin as possible to increase the effective moment arm of the aligner. The obvious advantage to power ridges is that attachments need not be placed or removed, and they are more aesthetically acceptable to the patient (Figure 19-61).

Root Parallelism

Another aspect of biomechanics, especially pertinent to extraction treatment, is to control tipping in order to achieve root parallelism. When a force is applied in an attempt to move a canine distally, the tooth will rotate about the center of resistance. It would require a sufficient moment to oppose the tipping movement. This is a more problematic area because in a typical mesiodistal movement as in an extraction scenario, the aligner contacts the tooth on a surface that is parallel to the direction of force. The result is that there is little, if any, moment arm created without the use of substantial attachments (Figures 19-62 to 19-66).

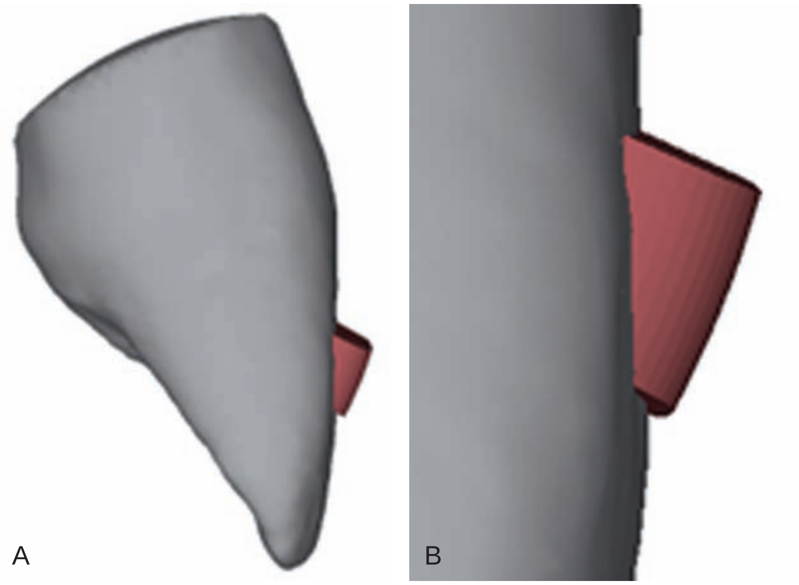


FIGURE 19-59 **A,** Occlusally beveled attachment. **B,** Occlusally beveled attachment close-up.

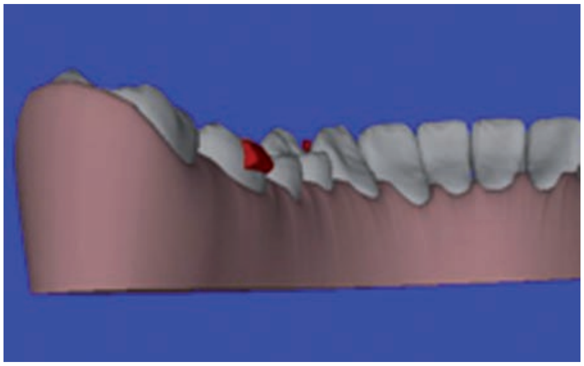


FIGURE 19-60 Beveled attachment on lingual of lower first molar.

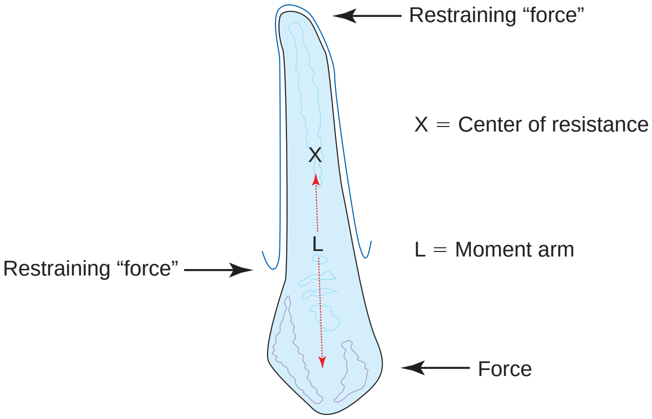


FIGURE 19-62 Force application against mesial of upper canine.

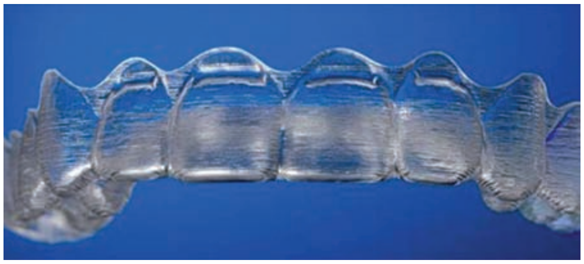


FIGURE 19-61 Power ridges.

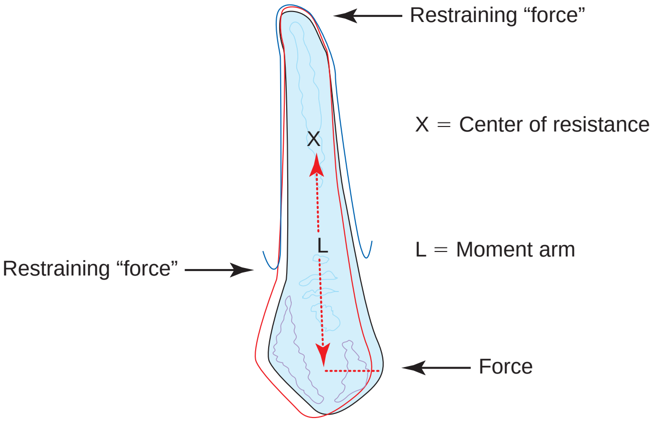


FIGURE 19-63 Effect of force application against mesial of upper canine.

An idea dating back to the late 1800s[19] was to place an attachment on the gingival aspect of a bracket extending toward the center of resistance in an attempt to decrease the amount of tipping when teeth are moved mesiodistally. These gingival extensions are often described as power arms. Power arms have been added to the force system with Invisalign in an attempt to alter the force–moment system (Figures 19-67 and 19-68). In theory, the addition of a power arm auxiliary

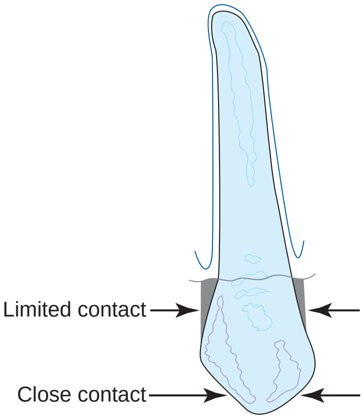


FIGURE 19-64 Diagram of aligner contact with upper canine.

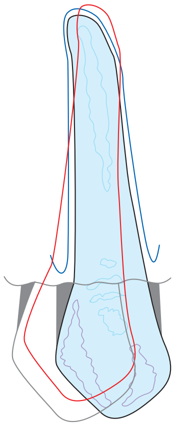


FIGURE 19-65 Displacement of aligner when force applied against mesial of upper canine.

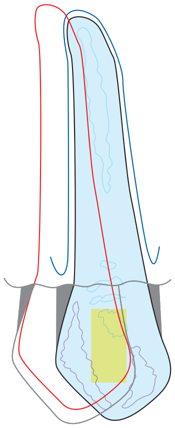


FIGURE 19-66 Controlled movement of upper canine with vertical attachment.

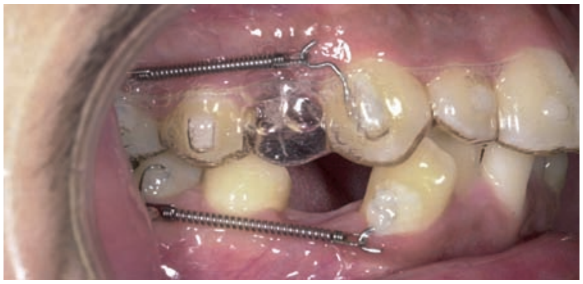


FIGURE 19-67 Hand-made power arms in combination with aligners.

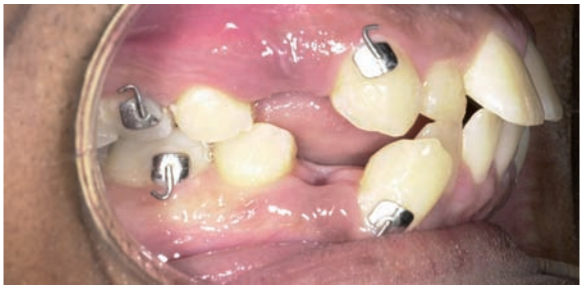


FIGURE 19-68 Manufactured power arms in combination with aligners.

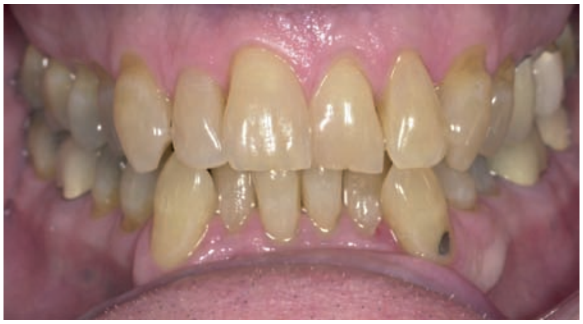


FIGURE 19-69 Clinical photograph of lower incisor crowding.

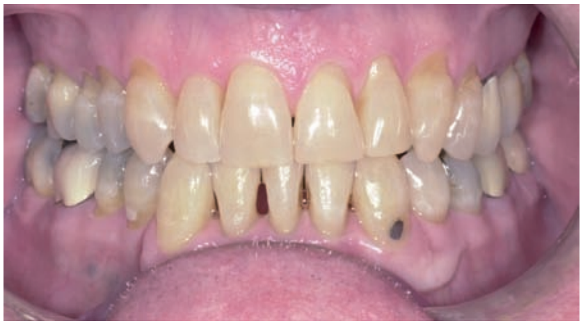


FIGURE 19-70 Clinical photograph of root parallelism after single lower incisor extraction.

accomplishes two things. First, it moves the application of force closer to the center of resistance. Second, it creates a secondary moment due to pressure against the distal of the aligner. Unfortunately, the clinical application is not as beneficial as with fixed appliances because molar root control is more difficult than canine root control.

We have successfully maintained root position of lower incisors during single incisor extraction treatment (Figures 19-69 and 19-70), and there have been reported cases of successful premolar extraction treatment using Invisalign.[20–22] Unfortunately, often canines remain upright during retraction into premolar spaces, while the molars, especially maxillary molars, tend to tip mesially.

This is frequently referred to as "dumping" (Figures 19-71 to 19-73). Dumping occurs even when the molars are simply being used as anchorage for anterior retraction. This is probably caused by the undesirable crown-to-root ratio combined with the large root surface area over which forces are distributed. This effect is similar to that seen when there are virtual collisions present that create a tooth size–to–aligner size discrepancy, as described earlier. Work is currently being done with various accentuated attachment designs, to demonstrate the ability to predictably avoid molar dumping by placing two 2-mm × 2-mm × 2-mm attachments on the upper first or second molars. This appears to offer significant benefits, possibly by providing a means to have a couple on the molar crown itself (Figure 19-74).

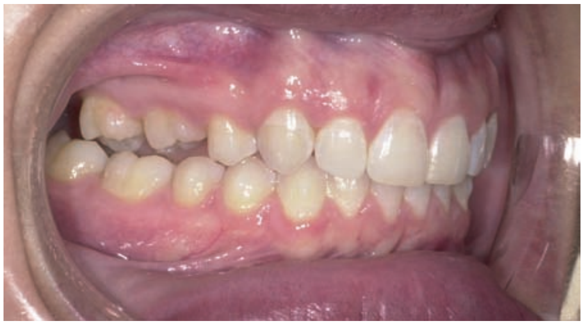


FIGURE 19-71 Mesial tipping of maxillary molar after premolar extraction.

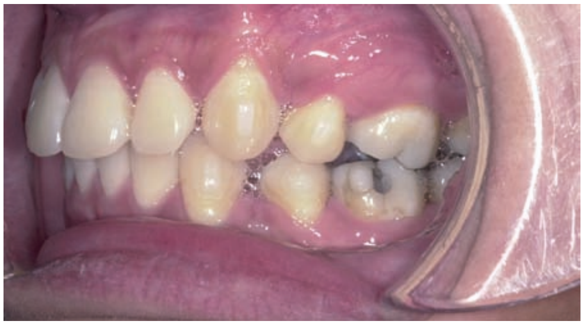


FIGURE 19-72 Mesial tipping of maxillary molars after premolar extraction.

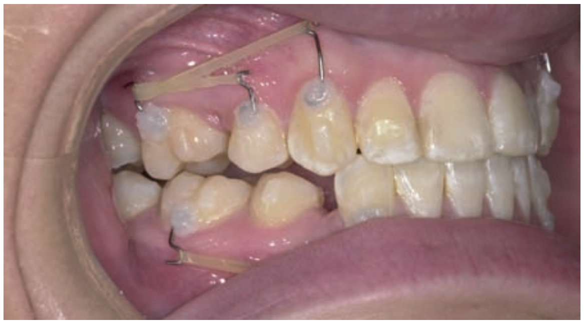


FIGURE 19-73 Mesial tipping of maxillary molars after premolar extraction.

Rotations

Correcting rotations with aligners can be problematic. There are two primary reasons for this. The first is that aligners produce tooth movement by the plastic being slightly distorted and then elastically rebounding back to the predetermined shape and carrying the tooth with it. In the case of rotations, the aligner is incapable of being distorted in a manner that can produce significant rotational movement. An analogous comparison would be attempting to rotate a tooth with a large steel archwire. Some have suggested that beveled attachments with the bevel turned 90 degrees (i.e., mesiodistally; Figure 19-75) would provide a surface to allow the aligner to rotate teeth. Even with a properly designed attachment, another problem with rotations is that the tooth root is not a cylinder, and because of dilacerations and root surface variations, there is no way the computer software can

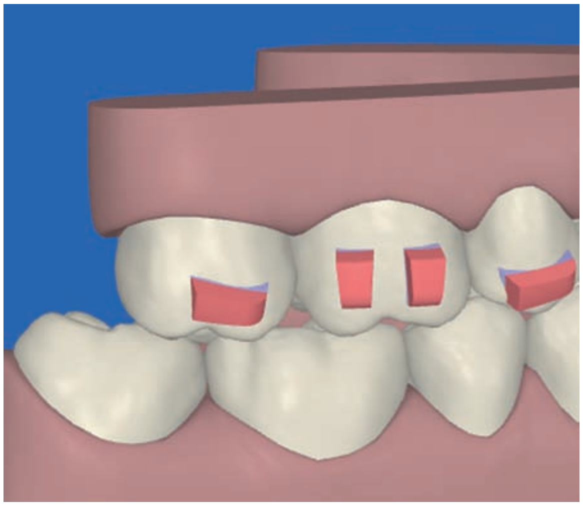


FIGURE 19-74 Twin attachment.

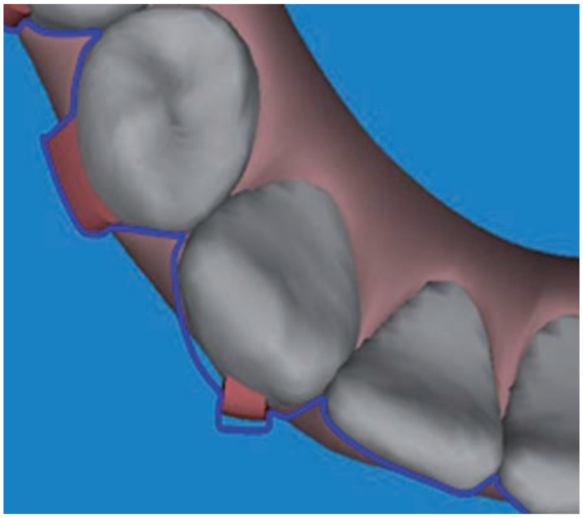


FIGURE 19-75 Rotation beveled attachment.

adequately estimate the true rotational long axis. In many cases what is thought of as a rotation of the tooth crown turns out to be bodily movement of the root surface; thus, estimating the proper rate of tooth movement becomes impossible. When this happens in fixed appliances, it simply takes longer for the tooth to rotate; when it happens with aligners, the aligner no longer fits the tooth. This results in lack of desired movement, but also, the aligner is now contacting different tooth surfaces than was intended. The result is either no movement or undesirable tooth movements. With many rotated teeth, there has typically been a need to use auxiliaries either before, during, or after aligner treatment in order to accomplish the rotational correction (Figures 19-76 and 19-77); however, with the advent of the newer optimized attachments, the predictability of rotational movements has improved.

Extrusions

Extrusions can also present problems with aligners. The reason for this is similar to that of rotations. In the same way that the aligner itself is incapable of elastic deformation in the direction needed for effective rotational movement, the aligner cannot stretch within the plastic itself so an elastic deformation in the direction needed for extrusion is not possible. One method being used to overcome this problem with some promising results is to use the gingivally beveled attachment to provide a longer surface that can be elastically deformed and provide an extrusive force on the tooth. In some cases a button bonded to the tooth together with an elastic will assist with the extrusion (Figures 19-78 to 19-80).

Other auxiliaries can be used to facilitate specific movements. Class II and Class III elastics are frequently needed just as they are with fixed appliances. One can either attach the elastics directly to the aligner or attach

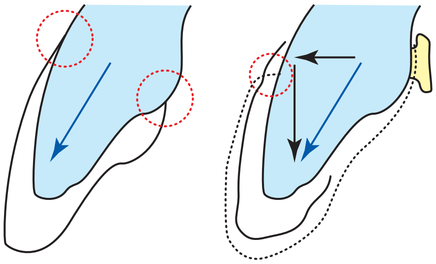


FIGURE 19-78 Extrusion auxiliary Diagram of extrusion mechanics with button and trimmed aligner.

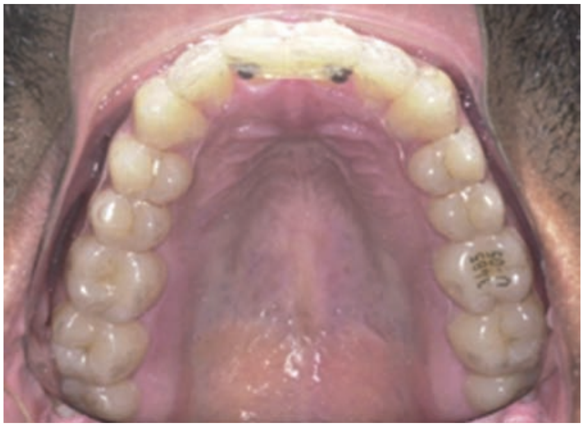


FIGURE 19-76 Rotational auxiliaries.

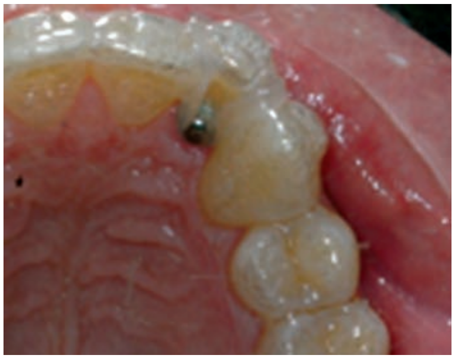


FIGURE 19-79 Extrusion auxiliary. Clinical photograph of extrusion mechanics with lingual button and trimmed aligner.

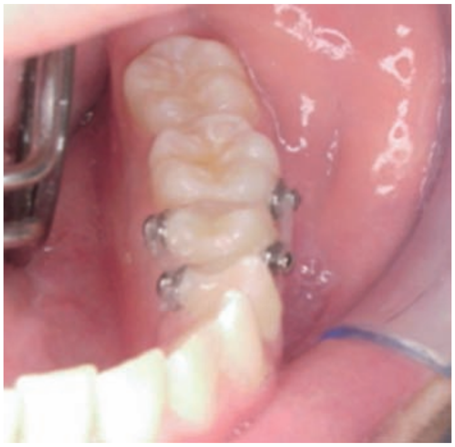


FIGURE 19-77 Rotational auxiliaries.

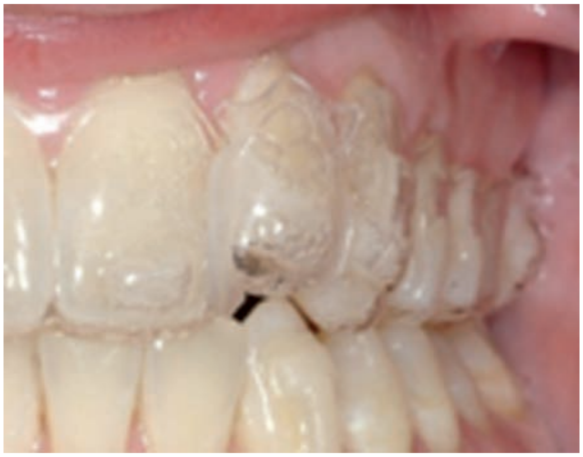


FIGURE 19-80 Extrusion auxiliary. Clinical photograph of extrusion mechanics with facial button and trimmed aligner.

elastics to buttons bonded to the teeth. Figures 19-81 to 19-83 illustrate the use of Class II elastics. Keep in mind that if the elastics are directly attached to the aligner, then attachments are generally required to prevent displacement of the aligner. Toe nail clippers can be used to cut slits in the aligners for elastic placement. They have the advantage of producing a slit that is both contoured to the papillary embrasure form and that has a blunt apex so the slit does not tend to propagate and split the aligner (see Figure 19-82). There is the additional advantage that patients can prepare their own aligners for elastics once they are shown where and how to make the slits. At the time of this writing, engineers at Align Technology have developed a prototype elastic hook that can be manufactured into the aligner, thus removing the necessity to prepare them clinically (see Figure 19-82, *B*). With buttons bonded to the teeth, each aligner must be trimmed around the button in the office prior to delivering the aligners to the patient.

Mini-screws can also be used effectively with aligners in the same manner as they can with fixed appliances, either planned initially as part of the treatment or to help with movements that are not progressing as desired. They can be used with aligners alone or in combination with other auxiliaries to simplify the movements the aligners are required to accomplish. The two most common uses of mini-screws with aligners are for vertical and anteroposterior movements. One such example is the extrusion of an upper canine, a movement that would be virtually impossible with aligners alone. Figures 19-84 to 19-86 demonstrate placing a mini-screw in the

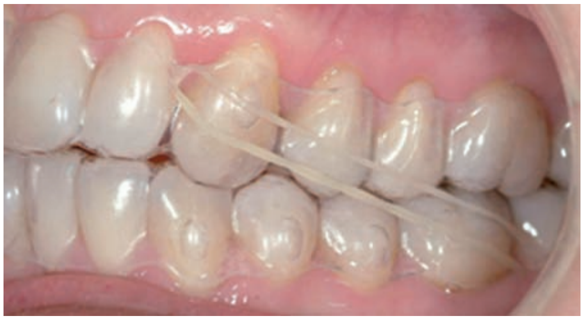


FIGURE 19-81 Class II elastics on aligners.

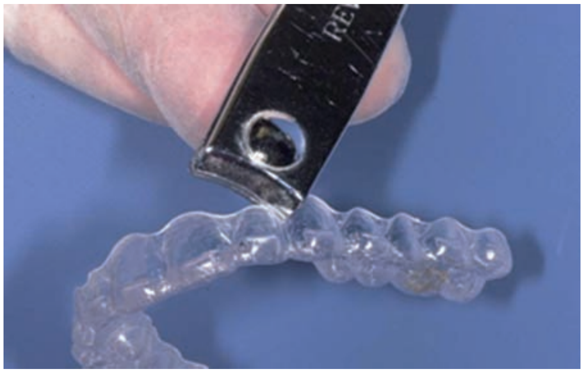


FIGURE 19-82 Preparing aligner for Class II elastics.

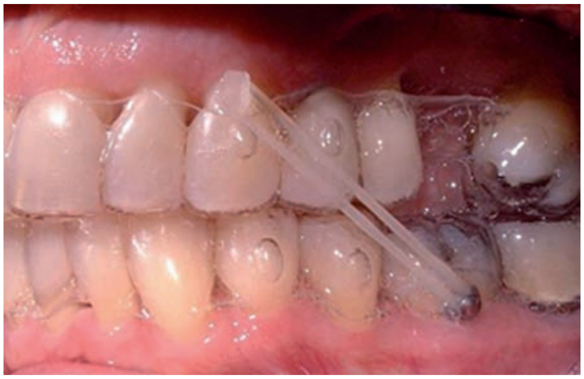


FIGURE 19-83 Class II elastics on buttons.

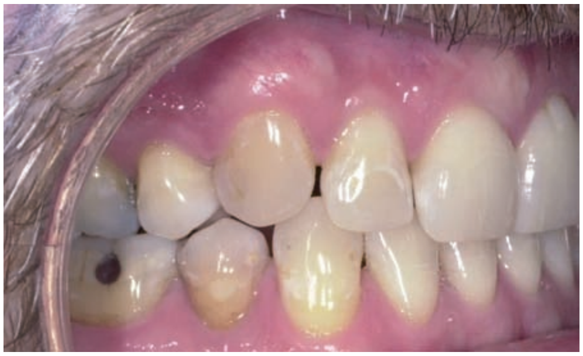


FIGURE 19-84 High canine.

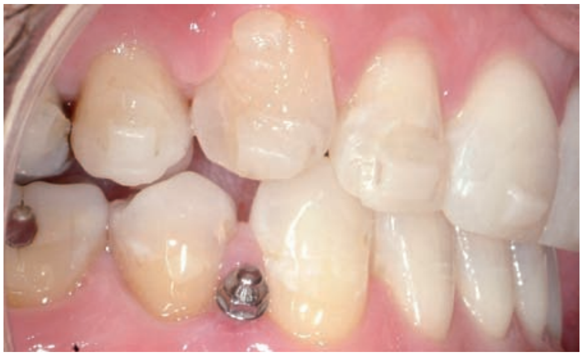


FIGURE 19-85 Canine with mini-screw placed.

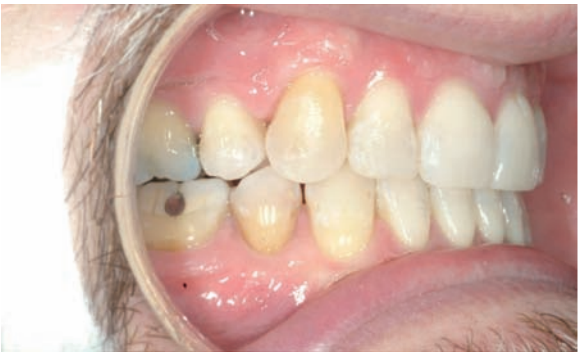


FIGURE 19-86 Final with canine extruded.

lower arch and then running a rubber band from a clear button near the gingival on the upper canine to the mini-screw while the aligner guides the tooth into the correct position.

Another vertical movement that is easily enhanced with mini-screws is the intrusion of molars that have supererupted into an edentulous space. Figures 19-87 to 19-89 illustrate placing a mini-screw on the buccal and lingual of an upper molar. The patient then wears an elastic from one mini-screw overtop of the aligner to the other mini-screw. Many of these patients need to undergo significant restorative treatment, and wearing aligners during the orthodontic setup is often preferred by the patient to wearing fixed appliances.

There are occasions when mini-screws can expedite Class II correction. The first example involves placing a Carriere Distalizer (Class One Orthodontics, Lubbock, TX) in the upper arch along with a mini-screw in the lower arch in the molar or retromolar area. A Class II elastic is then worn 24 hours a day, and generally a correction to Class I molar and canine can be expected in around 12 weeks. Once the anteroposterior correction has been accomplished, then arch alignment and finishing can be accomplished with Invisalign (Figures 19-90 to 19-93).

Another application of mini-screws with aligners is to correct an arch asymmetry by enhancing the distalization of one side. This can be accomplished by placing a

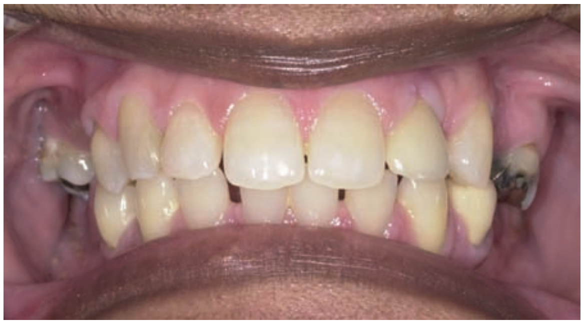


FIGURE 19-87 Supererupted molar.

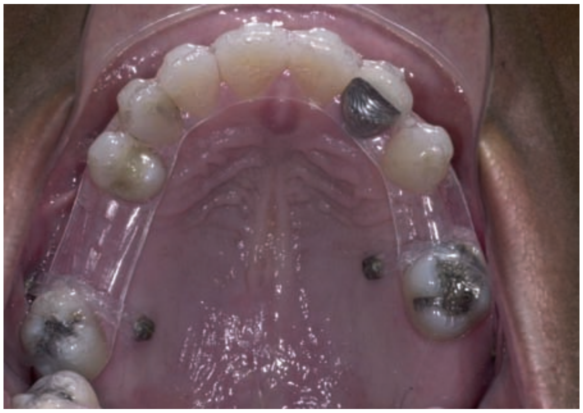


FIGURE 19-88 Supererupted molar with mini-screws and aligners.

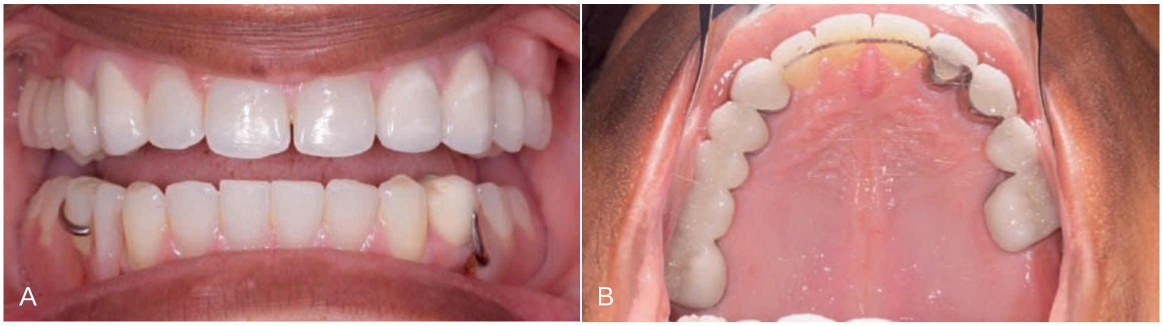


FIGURE 19-89 **A,** Final restoration of supererupted molar with mini-screws and aligners. **B,** Final restoration of supererupted molar with mini-screws and aligners.

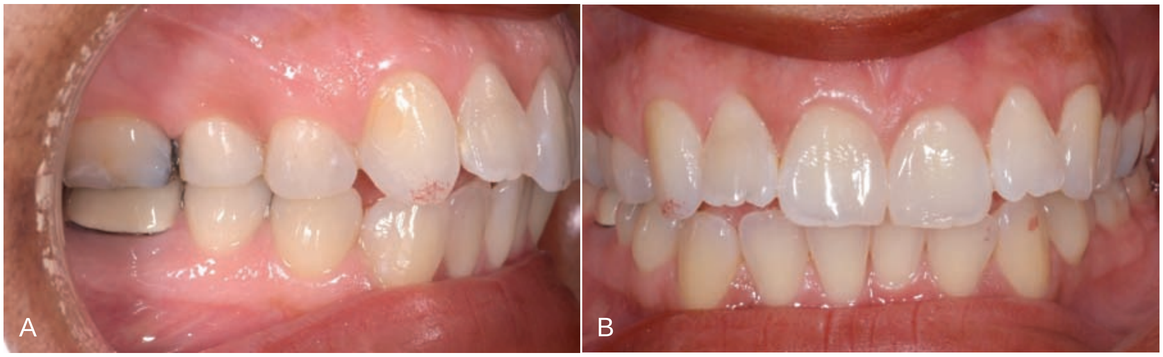


FIGURE 19-90 **A,** Initial class II malocclusion. **B,** Initial class II malocclusion.

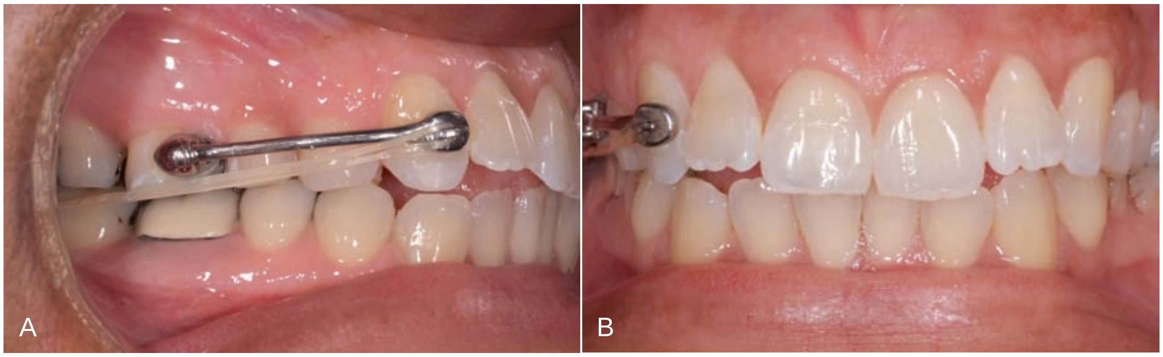


FIGURE 19-91 **A, B,** Carriere distalizer and mini-screw placed.

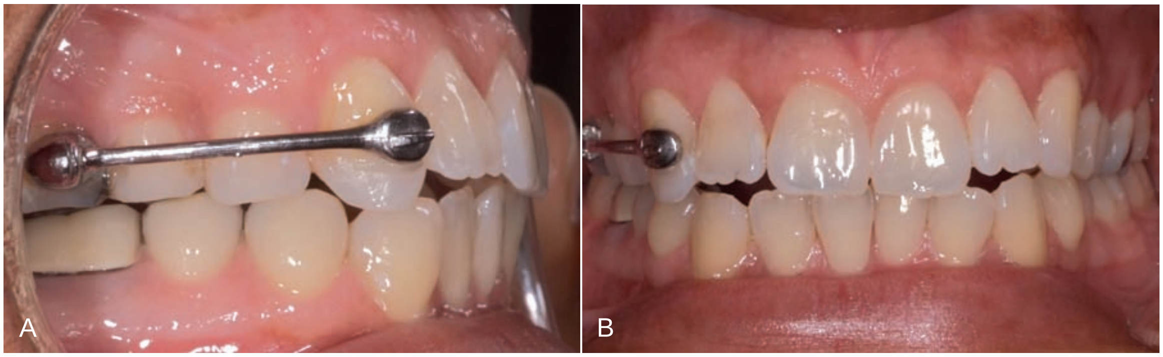


FIGURE 19-92 **A, B,** Class II corrected to Class I.

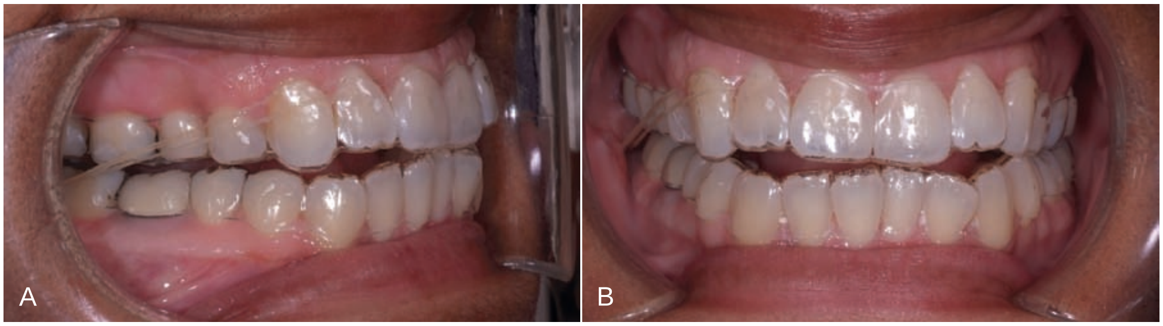


FIGURE 19-93 **A, B,** Holding aligner placed with class II elastic.

mini-screw in the retromolar area, bonding buttons on the facial and lingual of the upper first or second molar, and then connecting an elastic chain from the buttons to the mini-screw. If the intended movement is planned into the aligner treatment, the mini-screw provides the anchorage and allows simultaneous movement in the ClinCheck to reduce treatment time (Figures 19-94 to 19-96).

The previous images demonstrate a few examples of using mini-screws along with aligners to accomplish otherwise difficult movements. There are obviously multiple other applications of mini-screws with aligners.

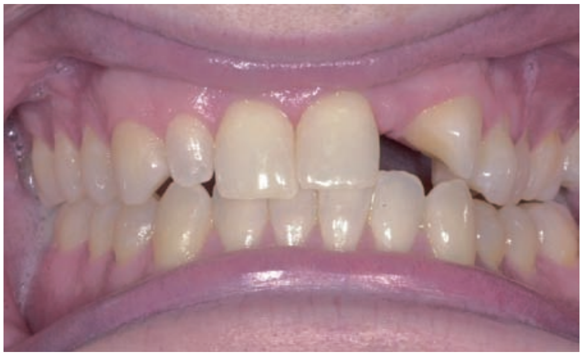


FIGURE 19-94 Pretreatment.

Invisalign Teen*

Invisalign Teen is not so much a different appliance as it is a specific feature set. Originally Invisalign was anticipated for use with adults and was approved by the FDA for those individuals with a fully erupted permanent dentition. It soon became apparent that there were certain benefits in being able to treat the late mixed dentition with aligners as well. The shortcomings that had to be overcome were anticipating tooth eruption of one or more permanent teeth, being able to monitor compliance in order to discuss progress (or lack thereof) with parents, proper control of torque without the need for attachments when crowns were not yet fully exposed, and, finally, avoiding practice management issues over lost aligners. Eruption tabs are used to prevent super-eruption of unerupted second molars (Figure 19-97). Tooth forms of approximate anticipated crown size are used to both create/hold room and guide eruption of actively erupting second premolars and canines, planning for refinement aligners with proper fit once the teeth are adequately erupted to properly capture the crowns in the impression. Wear indicators are placed on the facial surfaces of the first molars (Figure 19-98). There are two different types of chemical indicators that turn from dark blue to clear as the aligners are worn and are designed so that creative teenagers cannot realistically figure out a method to have both indicators change without actually wearing the aligners. Torquing

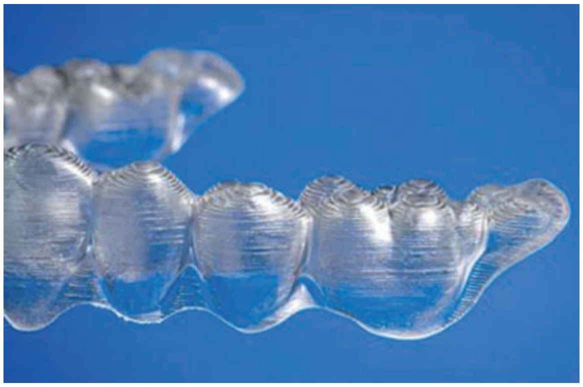


FIGURE 19-97 Eruption tabs.

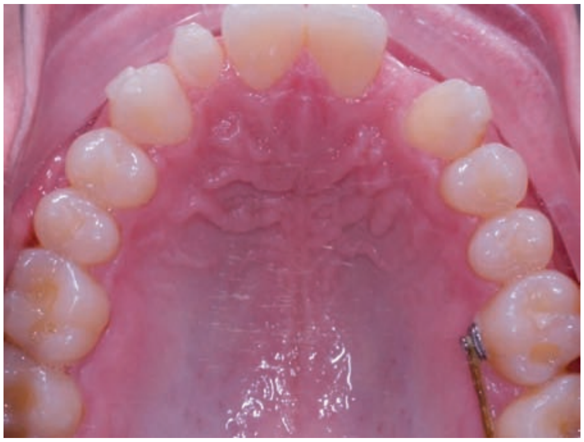


FIGURE 19-95 Elastic to mini-screw.

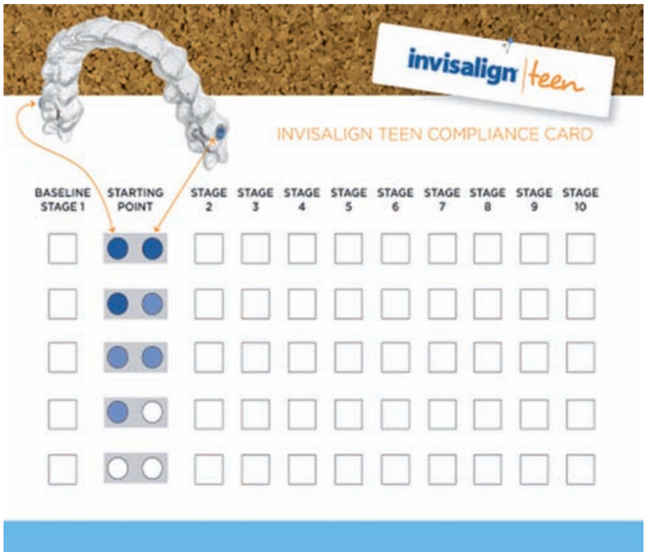


FIGURE 19-98 Compliance indicators.

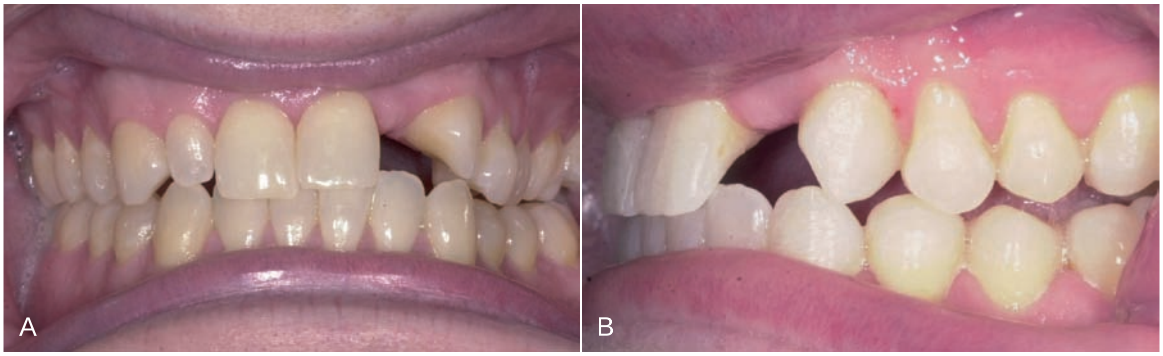


FIGURE 19-96 **A, B,** Asymmetry correction.

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*Invisalign Teen®, Align Technology, Inc., Santa Clara, CA ridges that were discussed previously were developed for the teen product and are a routine part of the feature set. The practice management part was actually quite easy. Align Technology charges a premium and provides free replacements for lost aligners … in reality, the patient prepays for the privilege of having them replaced if lost. There are many adults who can benefit from the features in Teen, and it is perfectly acceptable to order the teen product for an adult in order to avoid using anterior attachments or for any of the other features.

Understanding when and where to anticipate the use of aligners in combination with other techniques or auxiliaries is critical both to getting satisfactory results and to satisfying patients. Several variables combine to either produce acceptable desired results or unacceptable undesired tooth movements. We will review these with reference to specific movements. The first and most important variable is duration of wear. Aligners are not retainers and must be worn consistently for approximately 22 hours of a 24-hour period, essentially acting like fixed appliances. If not, results are extremely unpredictable. Patients who do not comply with wearing aligners for the required duration daily generally have less than desirable results. The next most important variables are clinical crown length and shape. The longer the clinical crown and the greater the natural undercuts to facilitate aligner retention, the more likely it is that the desired movement will take place, because there is a greater amount of surface area for the aligner to contact. Patients with very short clinical crowns are not good candidates to attempt some movements with Invisalign such as root paralleling with premolar extraction treatment. Single lower central incisor extraction tends to be successful because of the length of the clinical crowns of the lower incisors relative to the forces applied. Closing anterior spaces, especially with protrusive incisors that require some intrusion, is extremely predictable and would require no attachments. Closing minor anterior open bites is predictable because the side effect of aligner wear is often a posterior open bite due to having two layers of plastic between the teeth for an extended period of time, so the bite is closed by virtue of a slight autorotation of the mandible as the molars are intruded. With that in mind, when opening a deep bite, special consideration should be given to the virtual setup. If there is a deep curve of Spee, intruding lower second molars and lower incisors (using the aligner as if it were a reverse curve of Spee archwire) leaves only a small amount of extrusion of the premolars. Along with the reverse curve of Spee effect, one can request heavy posterior occlusal contacts to compensate for the side effect of creating a posterior open bite. This is accomplished by having the technician intentionally create virtual collisions between the upper and lower molars. As discussed previously, rotations are somewhat unpredictable as well. Often the decision is not whether to treat a patient with Invisalign, but rather what adjunctive treatment would be required to gain the best end results for the patient. There are times when a short period of fixed appliances are of benefit to treat multiple rotations, parallel roots, or localized extrusion, followed by comprehensive treatment with aligners. There are other times when it makes more sense to accomplish general alignment with aligners for a year or so and then use fixed appliances to detail out the unresponsive teeth. Still other times, aligners followed by a short period of fixed and then refinement with aligners is the best option. Much depends on patient demands and expectations, as well as doctor comfort with combination treatment. There are no hard and fast rules, however; my recommendation is to use each appliance to do what it does best and tailor treatment to use whichever appliance both meets the patient's personal needs and is the most efficient and effective in treating the orthodontic problem list at hand.

Periodontal Considerations

There is a body of evidence growing that orthodontic treatment with aligners has less detrimental periodontal impact than that of fixed appliances. Miethke and Vogt[23] and Miethke and Brauner[24] compared the periodontal health of patients who underwent treatment with aligners to that of patients who underwent treatment with both labial fixed appliances and with lingual fixed appliances and found that the periodontal risk was no greater than with labial appliances and was lower than that of lingual fixed appliances. Boyd[25,26] found that periodontal health could actually improve during the course of treatment with Invisalign. He attributed this to the patient's ability to remove the appliances and spend more time brushing and flossing their teeth and the aligner's ability to maintain an invisible appearance to the appliances.

SUMMARY

Not all malocclusions are amenable to treatment solely with the Invisalign system. Treatment of many malocclusions with proper tip, torque, arch form, and aesthetic crown inclination is possible to achieve with aligners. Besides the obvious aesthetic improvement over fixed appliances, there may also be periodontal health benefits associated with Invisalign treatment. Understanding both the process of aligner manufacturing along with the biomechanics of tooth movement with aligners and applying that knowledge to treatment planning and clinical execution should enable the clinician to design a treatment plan with aligners alone or in combination with fixed appliances to make both simple and complex treatment predictable and routine.

CASE STUDY 19-1

CLASS I MILD CROWDING

David E. Paquette

A 32.5-year-old woman presented with typical orthodontic relapse, having been treated as a teenager and then failing to wear retainers. She has a dentition that is ideally suited to treatment with aligners. She has long clinical crowns, few if any rotations, and generous undercuts near the gingival margins for retention of aligners. Figure 19-99, *A–H*, shows her initial presentation; Figure 19-100, *A–J*, shows

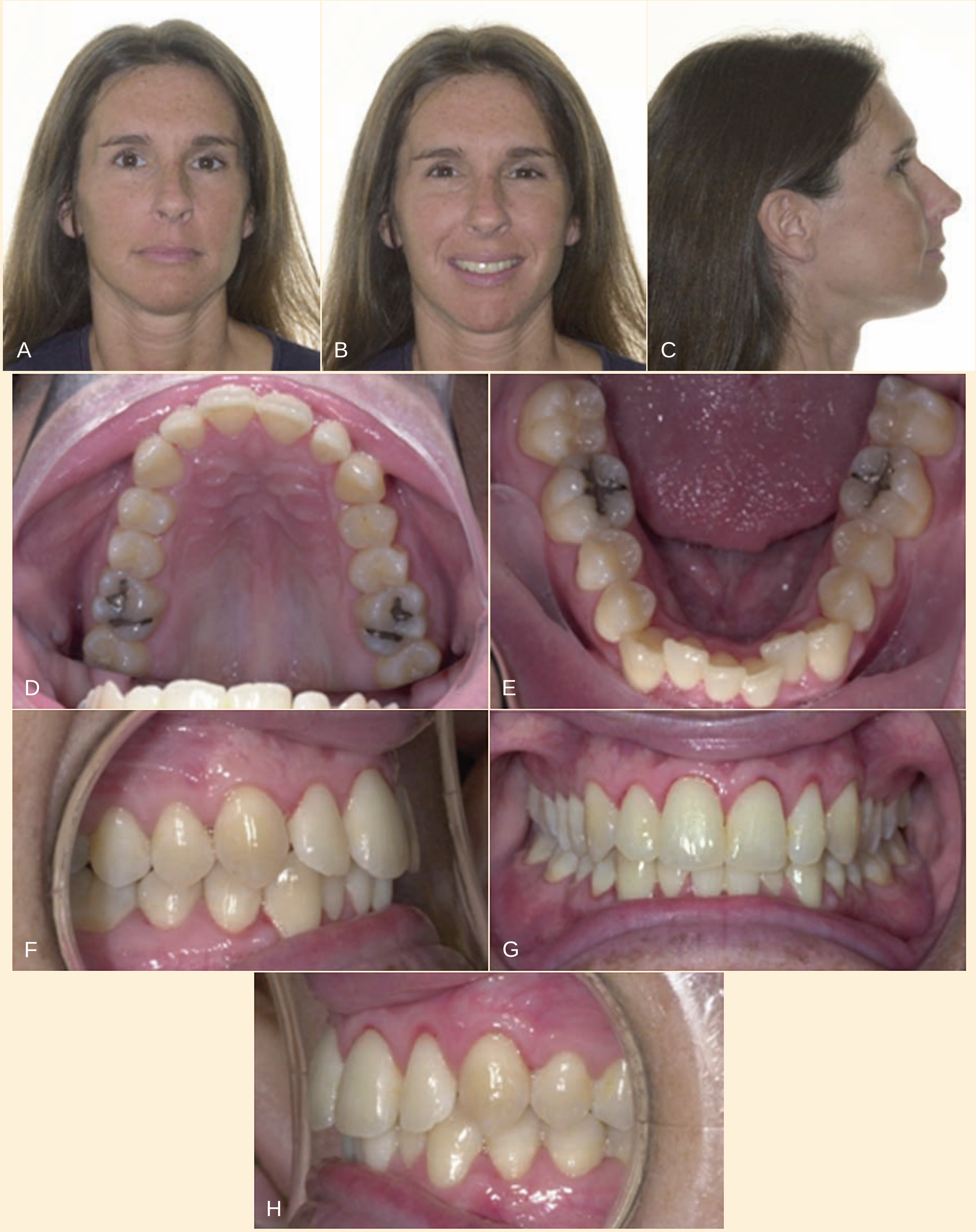


FIGURE 19-99 **A–H,** Initial photographs.

CASE STUDY 19-1 **CLASS I MILD CROWDING—cont'd**

her final results; Figure 19-101, *A,* shows her final ClinCheck; and 19-100, *B*, shows her ClinCheck with staging. Note that she required no attachments or auxiliaries. Her treatment took 12 months, 25 aligners, and 9 total appointments including examination, impressions, and retainer delivery.

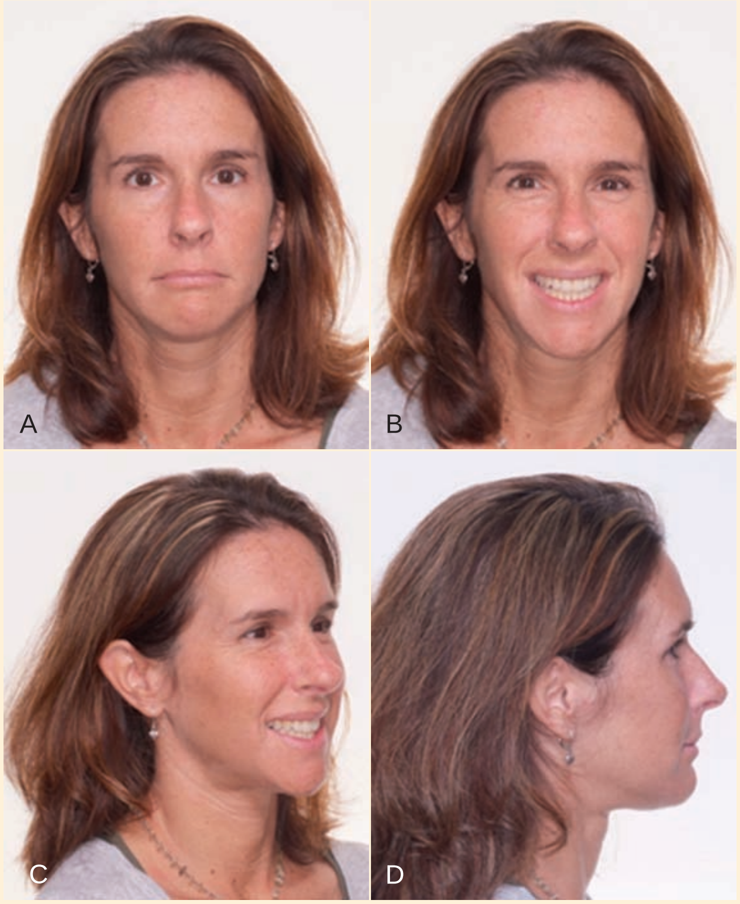


FIGURE 19-100 **A–J,** Final photographs.

Continued

CASE STUDY 19-1 CLASS I MILD CROWDING—cont'd

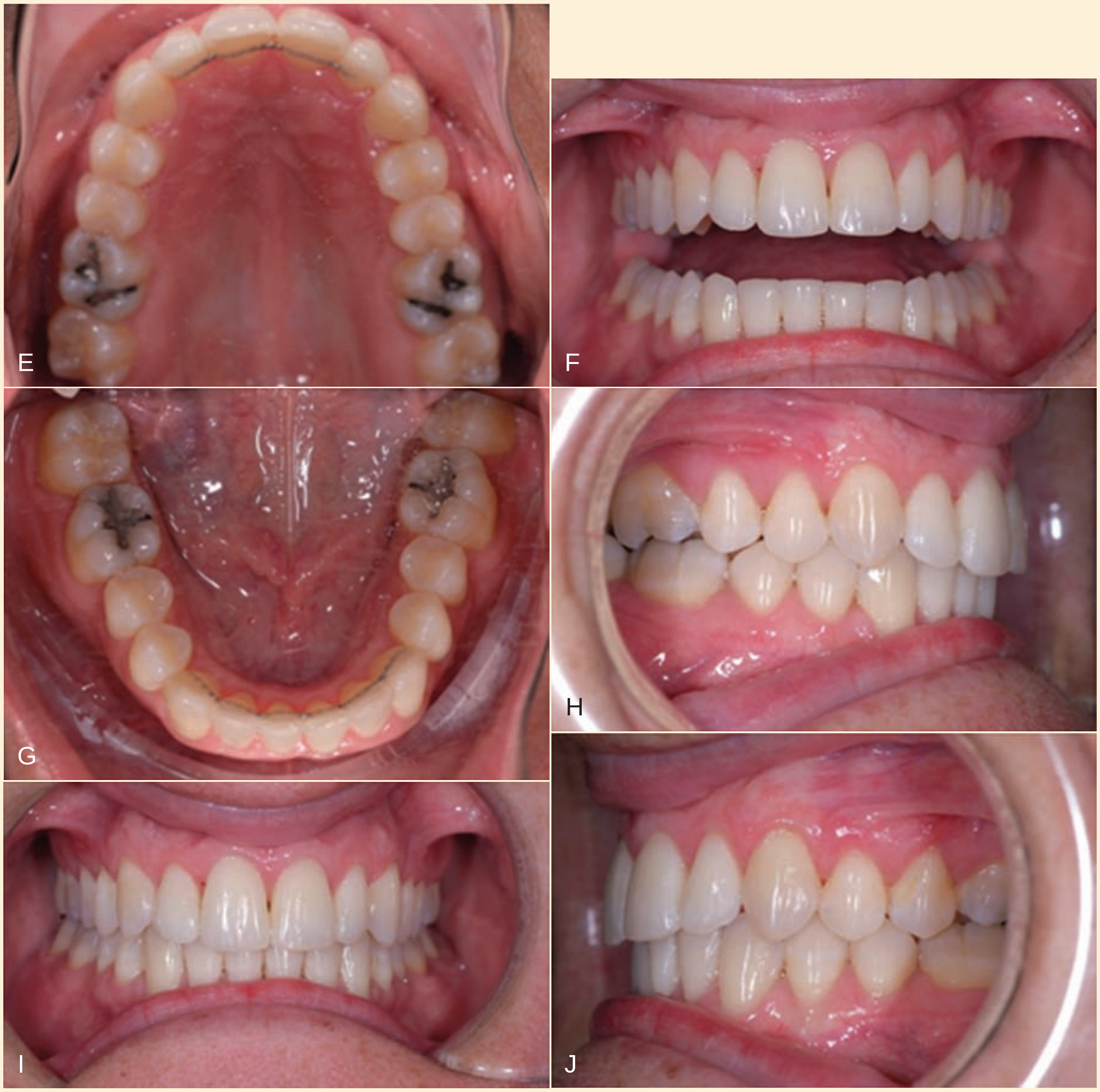


FIGURE 19-100, cont'd

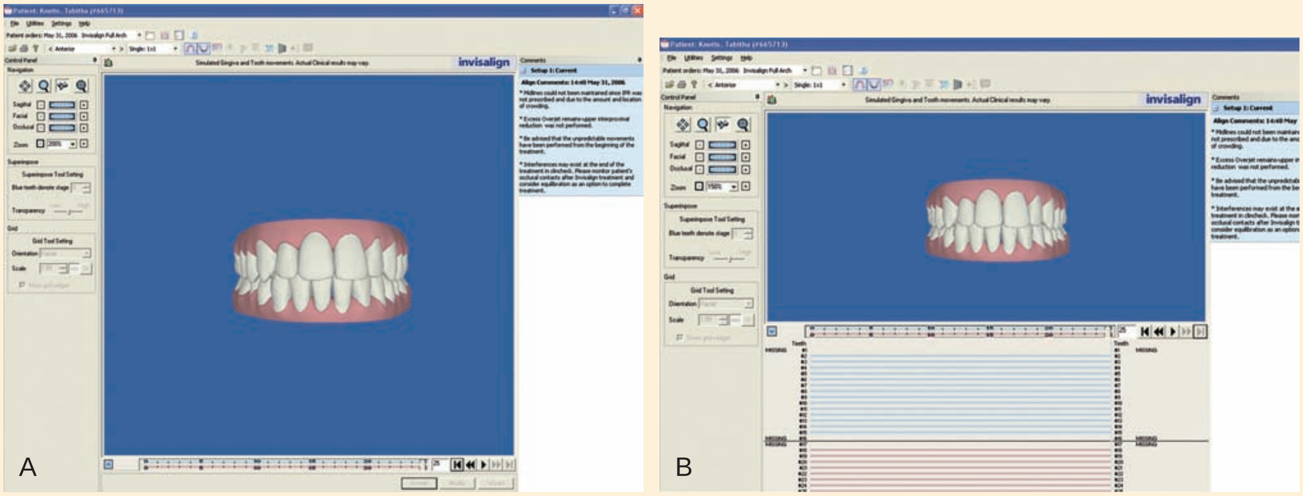

invisalign
Simulated Gingiva and Tooth movements. Actual Clinical results may vary.
invisalign
A
B

FIGURE 19-101 **A, B,** ClinCheck.

CASE STUDY 19-2 CLASS I MODERATE CROWDING

David E. Paquette

A 39-year-old female presented with typical orthodontic relapse, having been treated as a teenager and then failing to wear retainers. She presented with significant lower crowding and dark triangles between upper incisors. Figure 19-102, *A–H*, shows her initial presentation; Figure 19-103, *A–J*, shows her final results; Figure 19-104, *A*, shows her final ClinCheck; Figure 19-104, *B*, shows her ClinCheck with

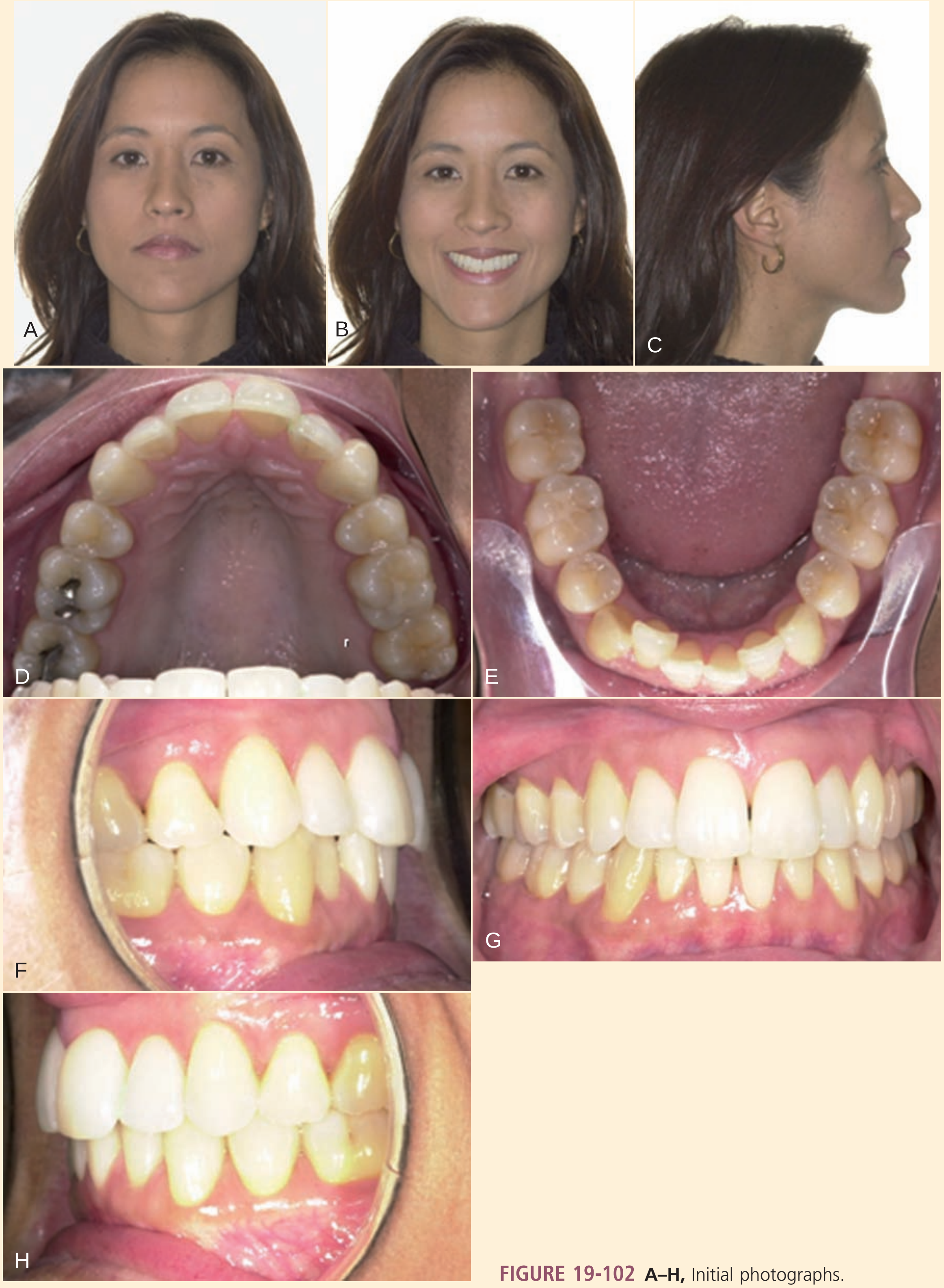


FIGURE 19-102 **A–H,** Initial photographs.

Continued

CASE STUDY 19-2 CLASS I MODERATE CROWDING—cont'd

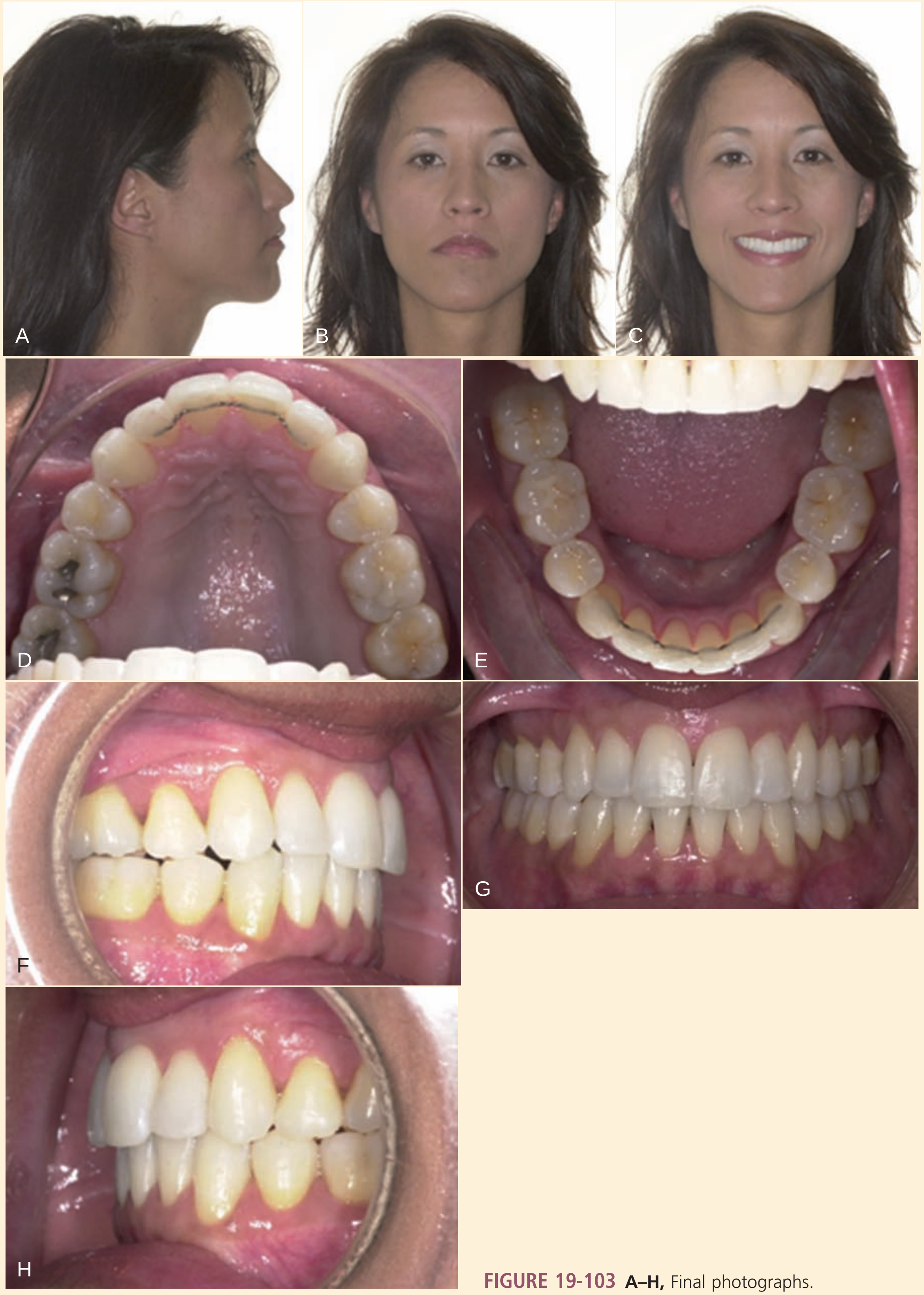


FIGURE 19-103 **A–H,** Final photographs.

CASE STUDY 19-2 CLASS I MODERATE CROWDING—cont'd

staging; and Figure 19-105 shows the patient at 2 years post treatment. In order to reduce dark triangles and control crown angulations, IPR was prescribed and attachments were appropriately placed. Her treatment took 11 months, 9 upper aligners, 21 lower aligners, and 9 total appointments, including examination, impressions, and retainer delivery.

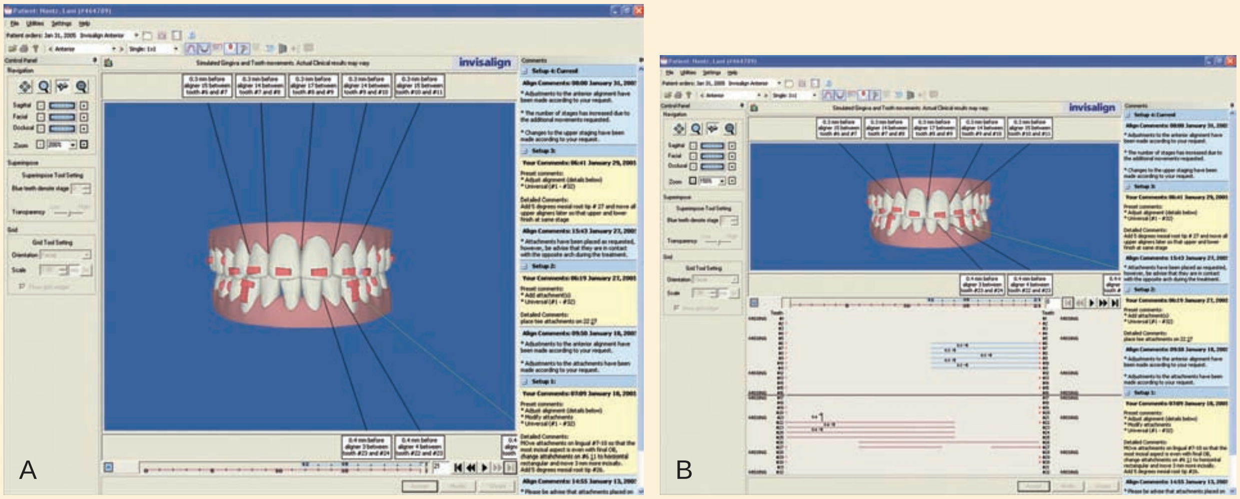


FIGURE 19-104 **A, B,** ClinCheck.

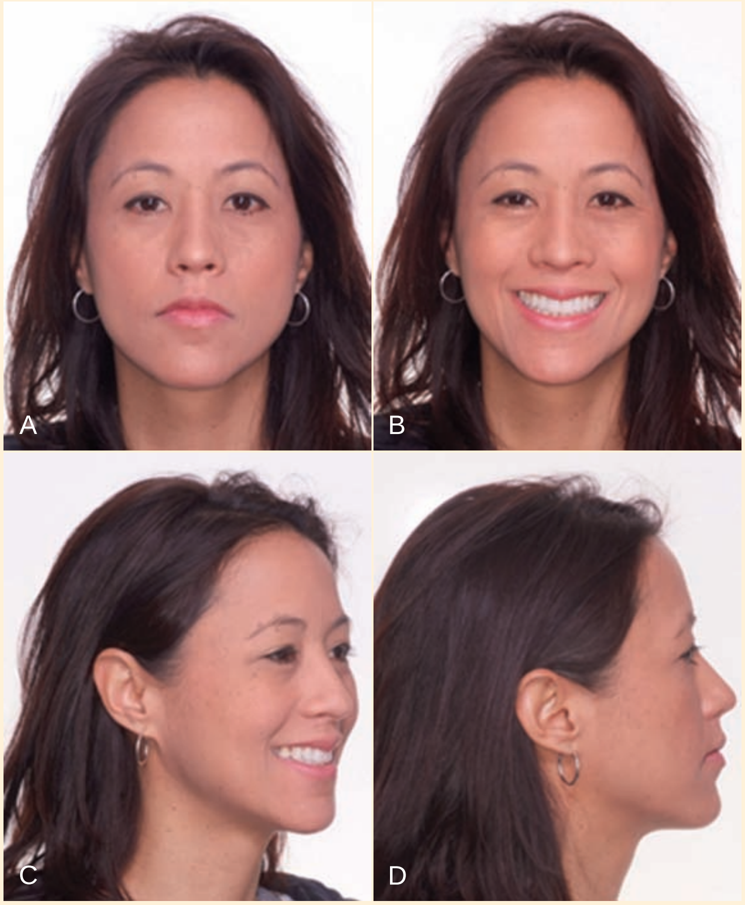


FIGURE 19-105 **A–J,** At 2 years post treatment.

Continued

CASE STUDY 19-2 **CLASS I MODERATE CROWDING—cont'd**

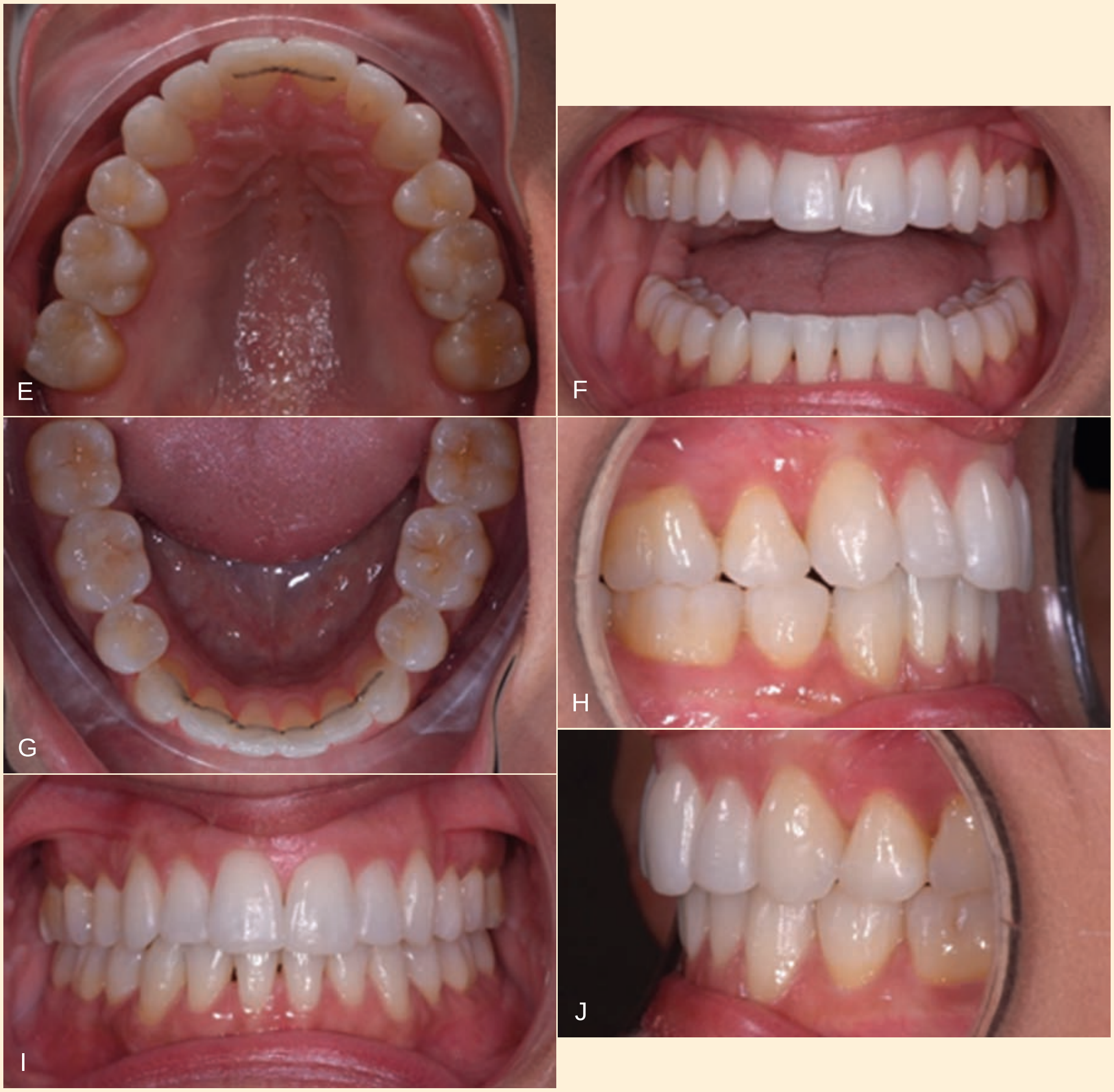


FIGURE 19-105, cont'd

CASE STUDY 19-3 CLASS I DEEP OVERBITE

David E. Paquette

JS presented as a 39-year-old male with no previous history of orthodontic treatment. He had a deep bite with increased curve of Spee, narrow arches and moderate crowding. Figure 19-106, *A–H*, show his initial presentation. Figure 107, *A–J*, shows his final results. Figure 19-108, *A*, shows his final ClinCheck and 19-107, *B*, shows his ClinCheck with staging. Figure 19-109, *A–C*, show the superimpositions and method for leveling curve of Spee. His treatment took 13 months, 26 aligners, and 10 total appointments including examination, impressions, and retainer delivery.

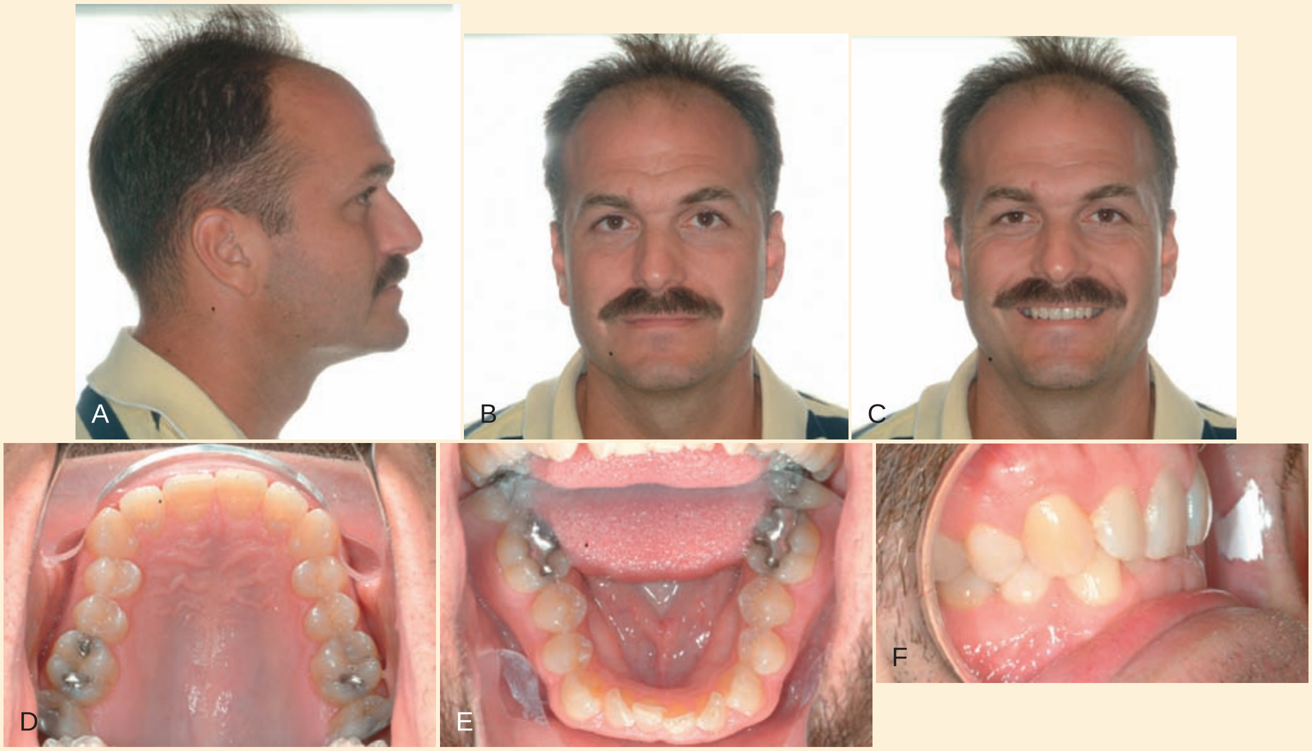


FIGURE 19-106 **A–F,** Initial photographs.

Continued

CASE STUDY 19-3 CLASS I DEEP OVERBITE—cont'd

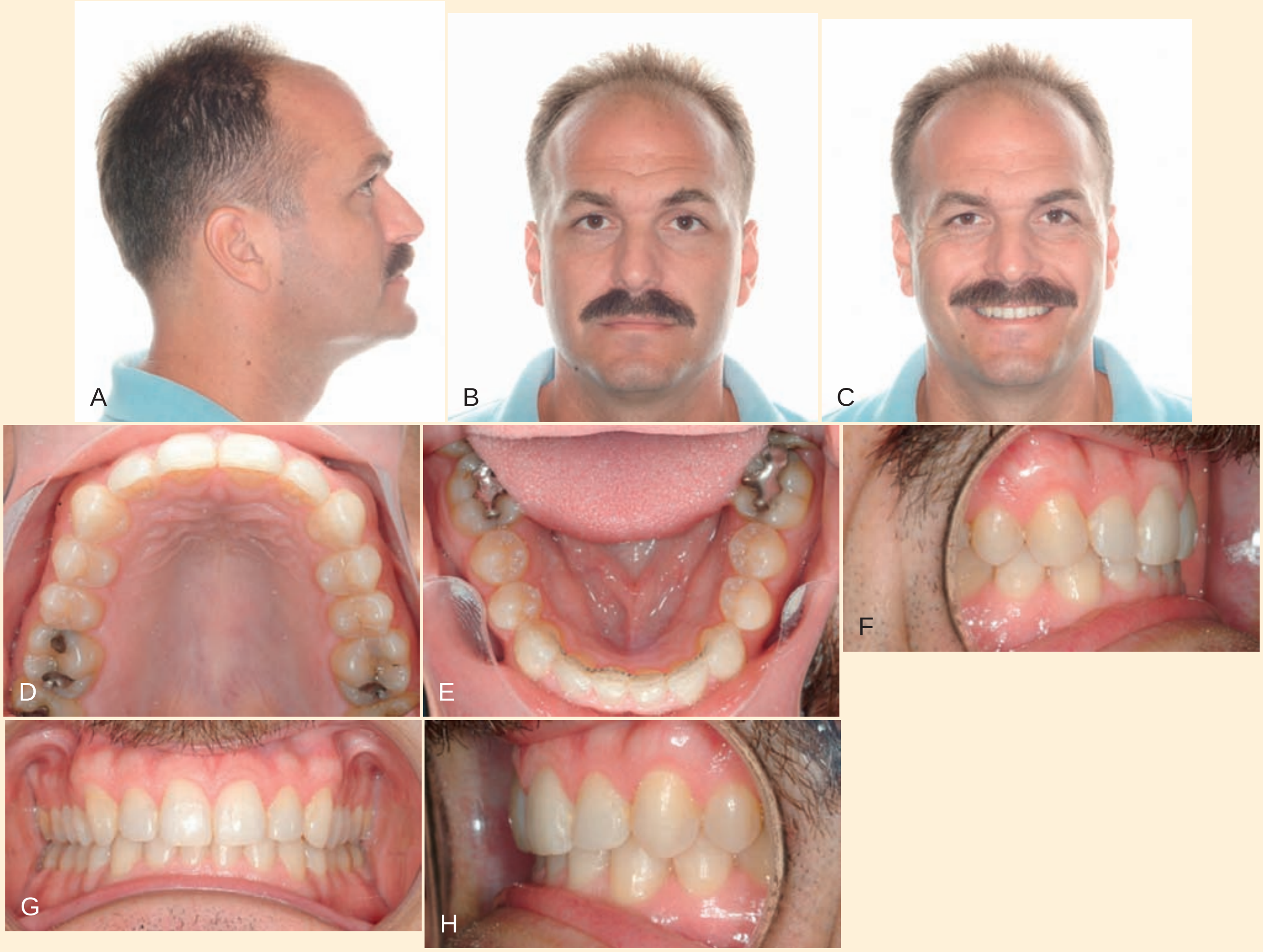
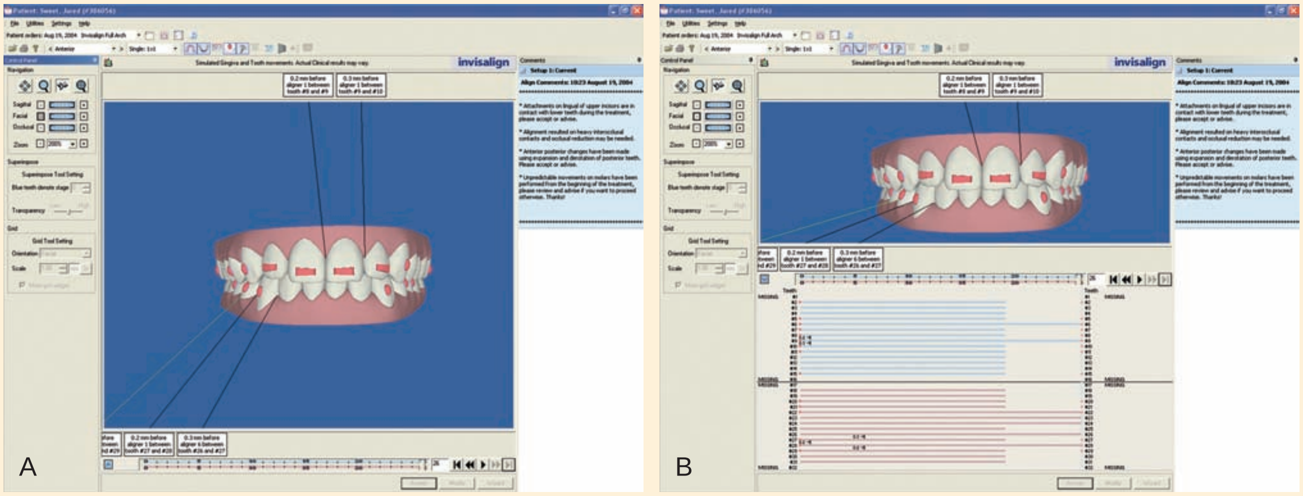


FIGURE 19-107 **A–H,** Final photographs.

CASE STUDY 19-3 CLASS I DEEP OVERBITE—cont'd



Simulated Gingiva and Tooth movements. Actual Clinical results may vary.

Comments

Setup 1: Current

Align Comments: 10:23 August 19, 2004

* Attachments on lingual of upper incisors are in contact with lower teeth during the treatment, please accept or advise.

* Alignment resulted on heavy interocclusal contacts and occlusal reduction may be needed.

* Anterior posterior changes have been made using expansion and derotation of posterior teeth. Please accept or advise.

* Unpredictable movements on molars have been performed from the beginning of the treatment, please review and advise if you want to proceed otherwise. Thanks!

invisalign
0.2 mm before aligner 1 between tooth #8 and #9
0.3 mm before aligner 1 between tooth #9 and #10
0.2 mm before aligner 1 between tooth #27 and #28
0.3 mm before aligner 6 between tooth #26 and #27
A
B

FIGURE 19-108 **A, B,** ClinCheck.

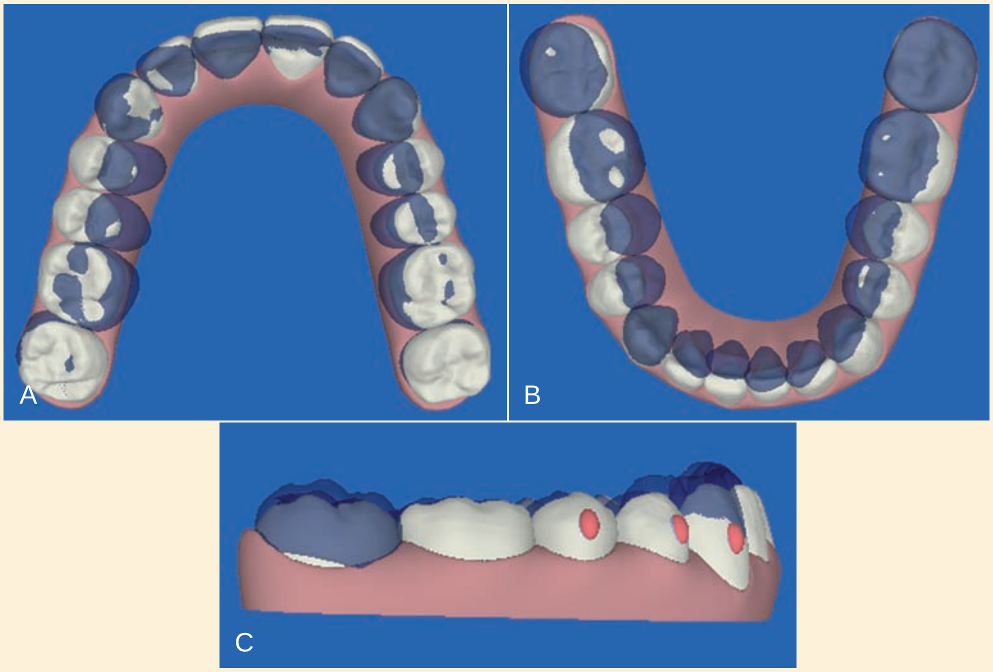


FIGURE 19-109 **A–C,** ClinCheck with superimposition.

CASE STUDY 19-4 CLASS II SUBDIVISION LEFT

David E. Paquette

CC presented as a 30y6m old female with no previous history of orthodontic treatment. She presented Class II subdivision left. Figure 19-110, *A–H*, shows her initial presentation. Figure 19-111, *A–H*, shows her final results. Figure 19-112, *A*, shows her final ClinCheck and 19-112, *B*, shows her ClinCheck with staging and Figure 19-113 shows how her class II elastics were worn. Her treatment took 23 months, 44 aligners (26 initial and 18 refinement) and 14 total appointments including examination, impressions, and retainer delivery.

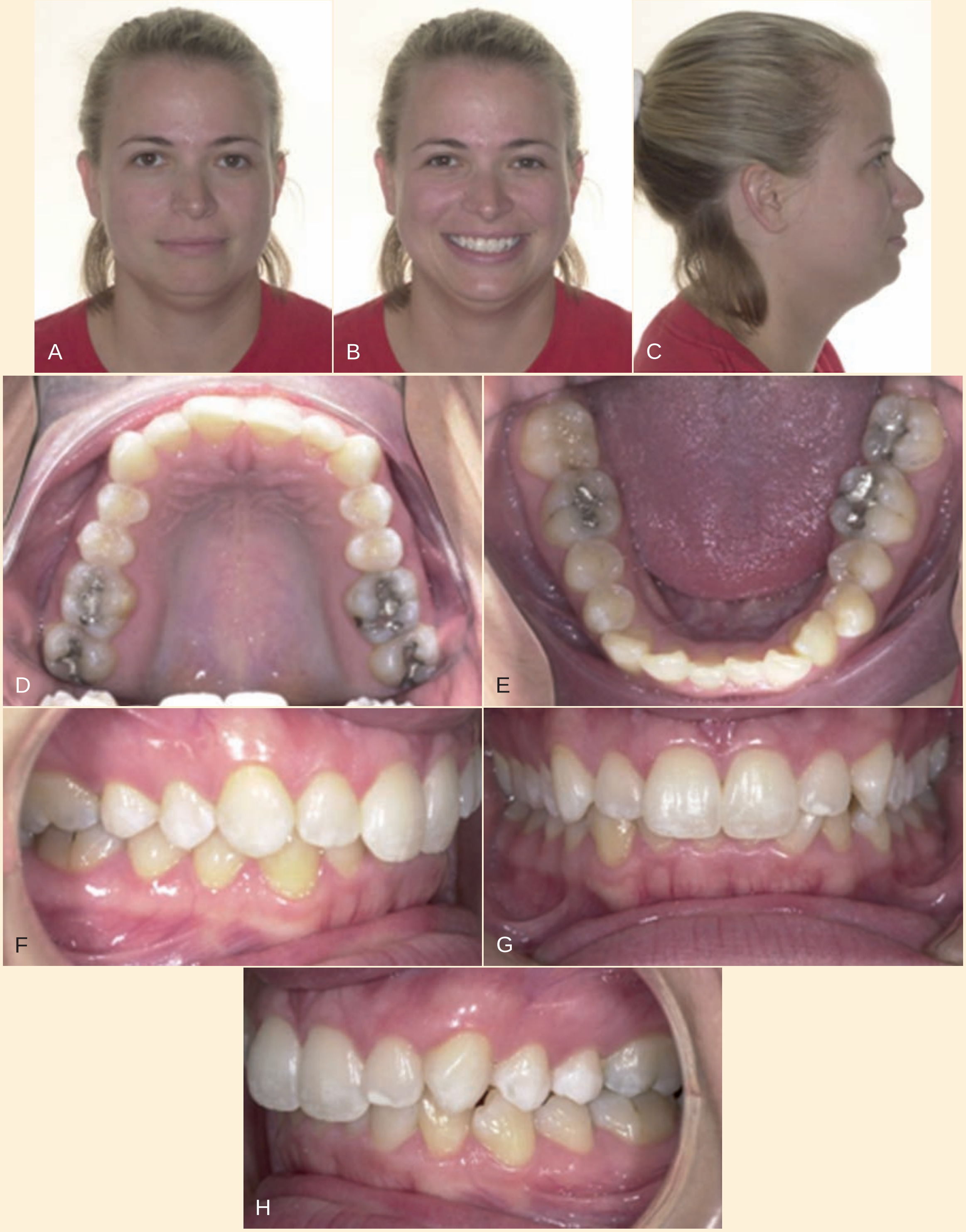


FIGURE 19-110 **A–H,** Initial photographs.

CASE STUDY 19-4

CLASS II SUBDIVISION LEFT—cont'd

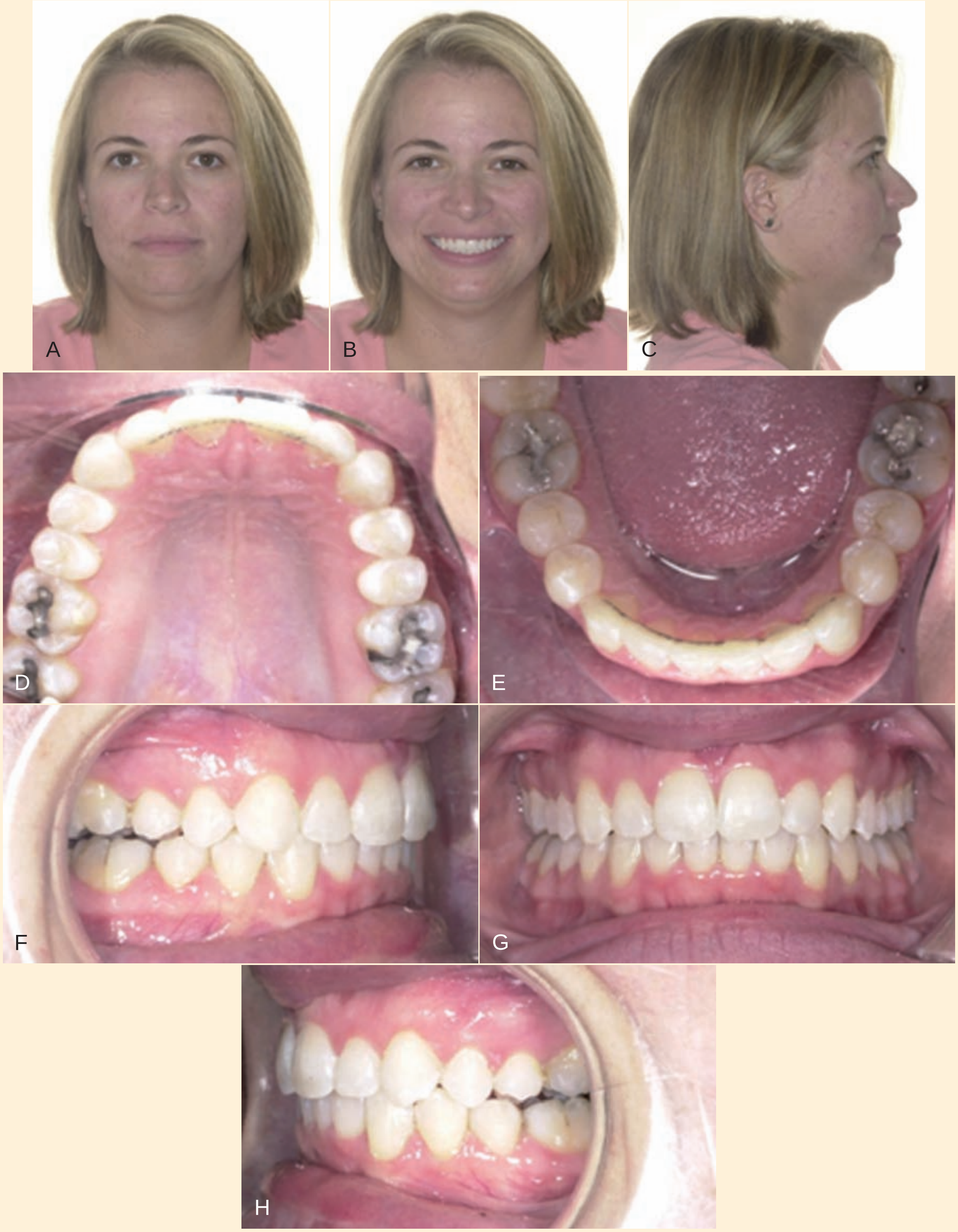
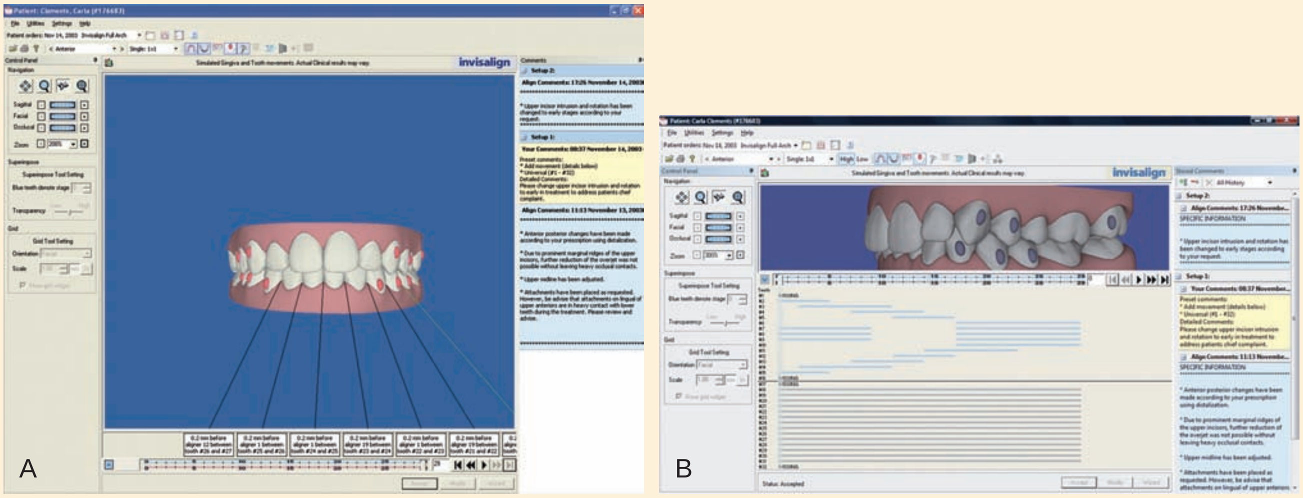


FIGURE 19-111 **A–H,** Final photographs.

Continued

CASE STUDY 19-4 CLASS II SUBDIVISION LEFT—cont'd


Patient: Clements, Carla (#176683)
File Utilities Settings Help
Patient orders: Nov 14, 2003 Invisalign Full Arch
Anterior
Single: 1x1
Control Panel
Navigation
Sagittal
Facial
Occlusal
Zoom
200%
Superimpose
Superimpose Tool Setting
Grid
Simulated Gingiva and Tooth movements. Actual Clinical results may vary.
invisalign
0.2 mm before aligner 12 between tooth #26 and #27
0.2 mm before aligner 1 between tooth #25 and #26
0.2 mm before aligner 1 between tooth #24 and #25
0.2 mm before aligner 19 between tooth #23 and #24
0.2 mm before aligner 1 between tooth #22 and #23
0.2 mm before aligner 19 between tooth #21 and #22
A
B
Status: Accepted

Comments

Setup 2:

Align Comments: 17:26 November 14, 2003

* Upper incisor intrusion and rotation has been changed to early stages according to your request.

Setup 1:

Your Comments: 08:37 November 14, 2003

Preset comments:
* Add movement (details below)
* Universal (#1 - #32)
Detailed Comments:
Please change upper incisor intrusion and rotation to early in treatment to address patients chief complaint.

Align Comments: 11:13 November 13, 2003

* Anterior posterior changes have been made according to your prescription using distalization.

* Due to prominent marginal ridges of the upper incisors, further reduction of the overjet was not possible without leaving heavy occlusal contacts.

* Upper midline has been adjusted.

* Attachments have been placed as requested. However, be advise that attachments on lingual of upper anteriors are in heavy contact with lower teeth during the treatment. Please review and advise.

FIGURE 19-112 **A, B,** ClinCheck.

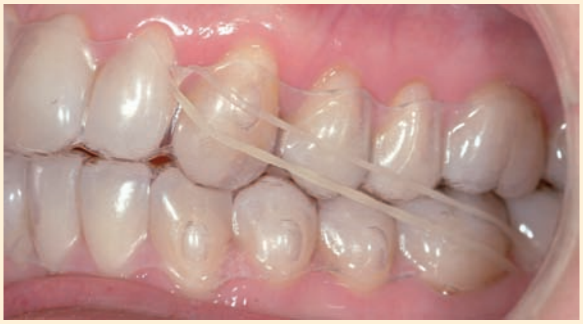


FIGURE 19-113 Class II elastics.

CASE STUDY 19-5

CLASS II DIVISION 2

David E. Paquette

SD presented as a 29y11m old female with no previous history of orthodontic treatment. She presented with a Class II div 2 crowded malocclusion with her lower midline 2 mm to her right. Figure 19-114, *A–H*, shows her initial presentation. Figure 19-115, *A*, shows her final ClinCheck and 19-114B shows her ClinCheck with staging. Figure 19-116, *A–J*, shows her prerefinement condition. Note the lack of

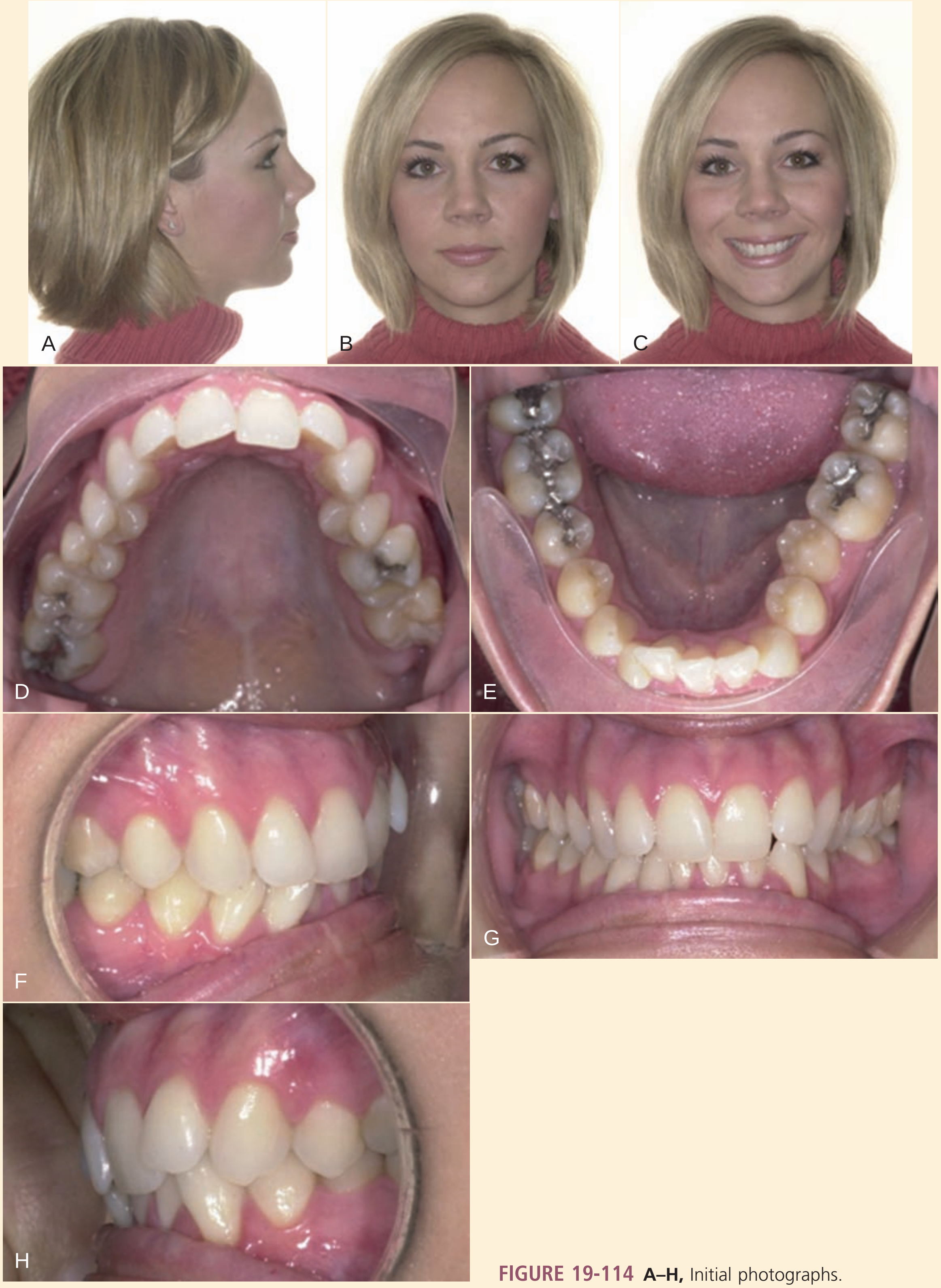


FIGURE 19-114 **A–H,** Initial photographs.

Continued

CASE STUDY 19-5 CLASS II DIVISION 2—cont'd

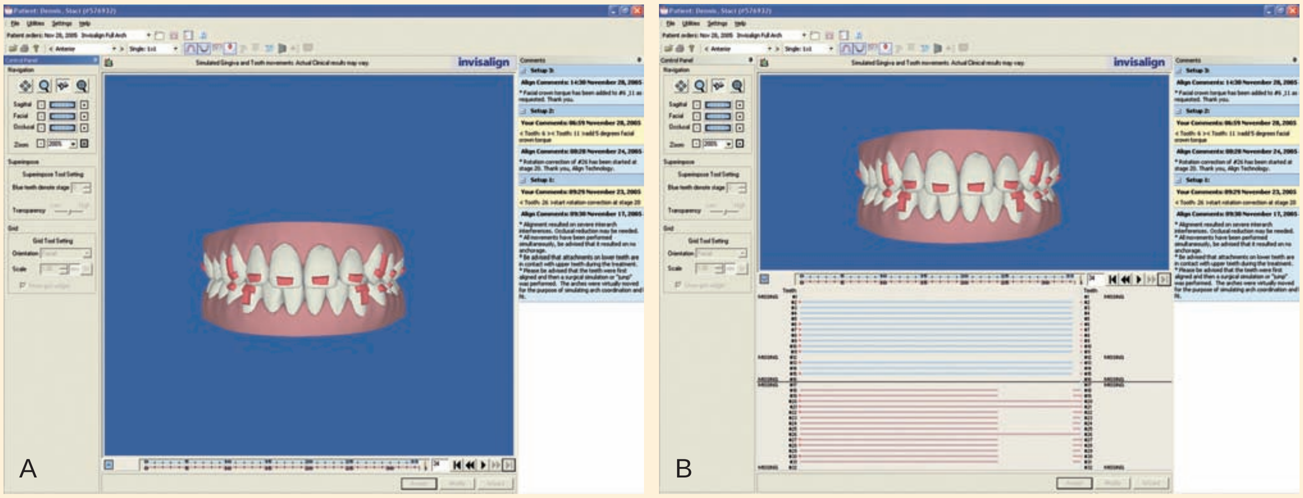


FIGURE 19-115 **A, B,** ClinCheck.

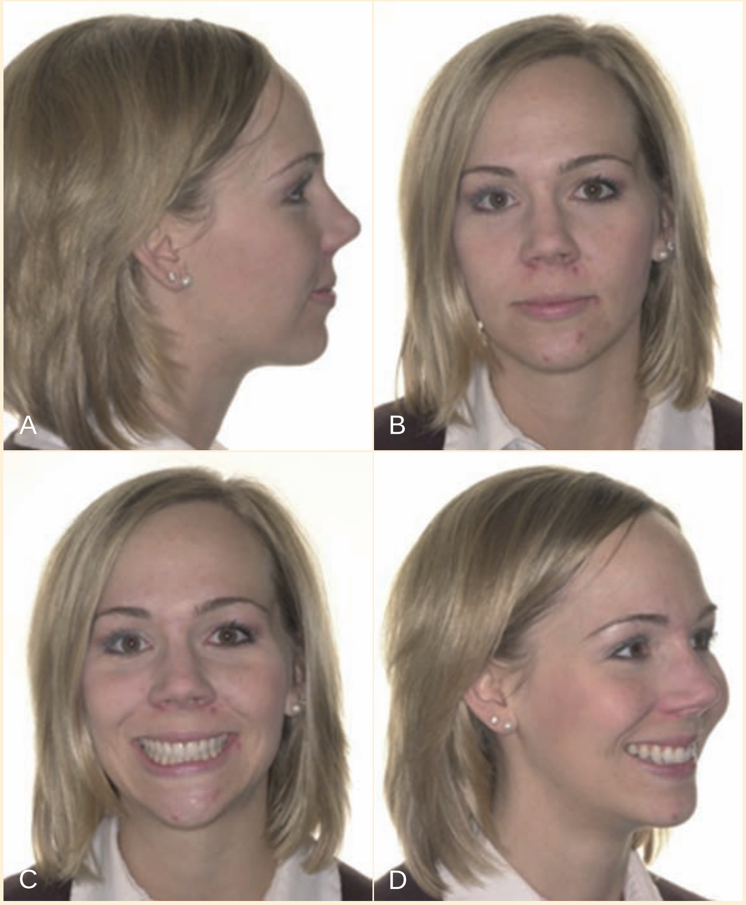


FIGURE 19-116 **A–J,** Refinement.

CASE STUDY 19-5 CLASS II DIVISION 2—cont'd

response of tooth number 26 to attempted rotation with aligners. Figure 19-117, *A*, shows her final ClinCheck and 117, *B*, shows her ClinCheck with staging and Figure 19-118, *A–J*, shows her response to aligner treatment prior to placing fixed appliances number 21-28 to correct the rotation of number 26. Figure 19-119, *A-H*, shows her final results. Her treatment took 23 months, 42 aligners (26 initial and 16 refinement), 6 weeks of lower partial fixed appliances, and 14 total appointments including examination, impressions, fixed appliances, and retainer delivery.

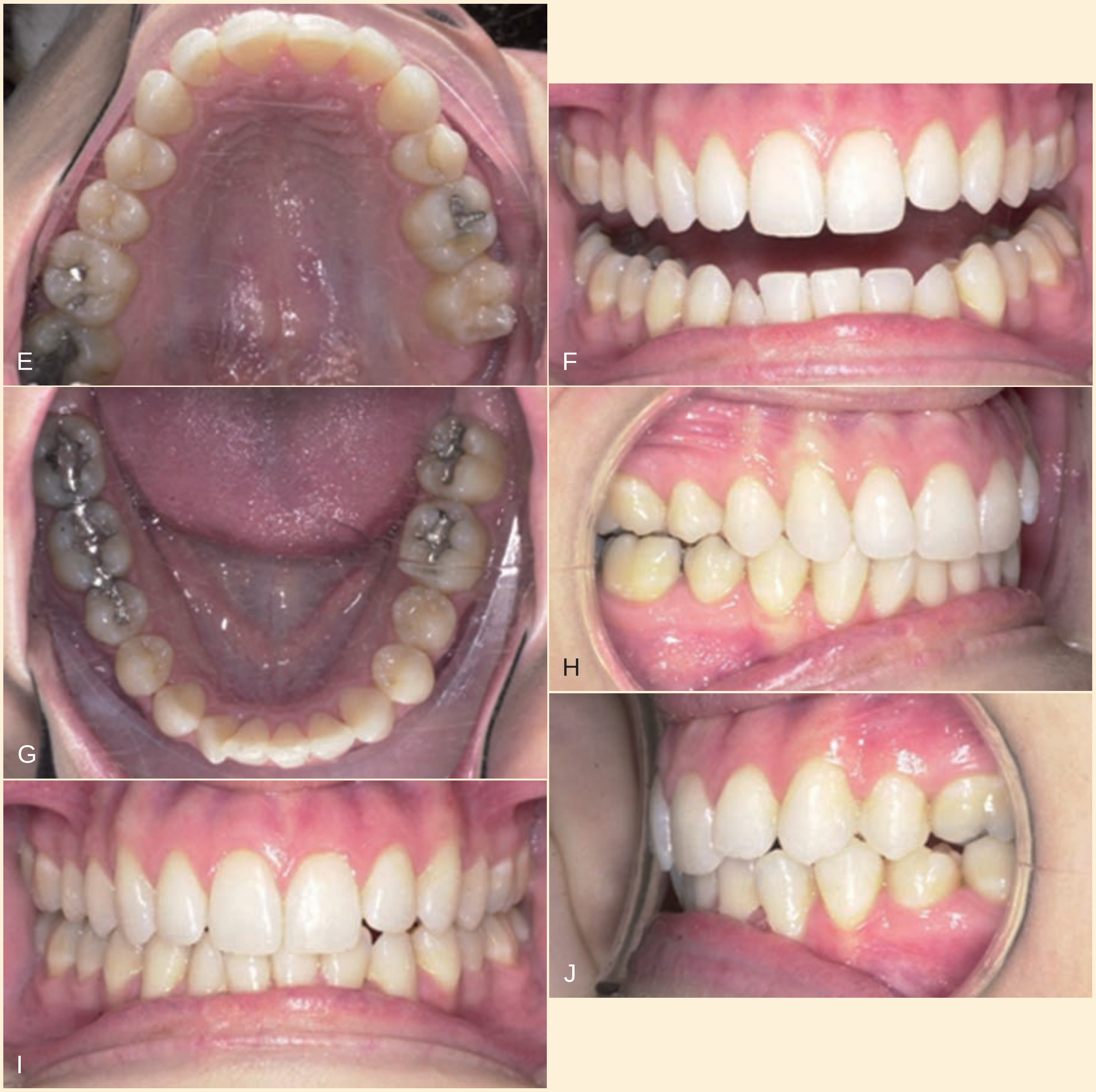


FIGURE 19-116, cont'd

Continued

CASE STUDY 19-5 CLASS II DIVISION 2—cont'd

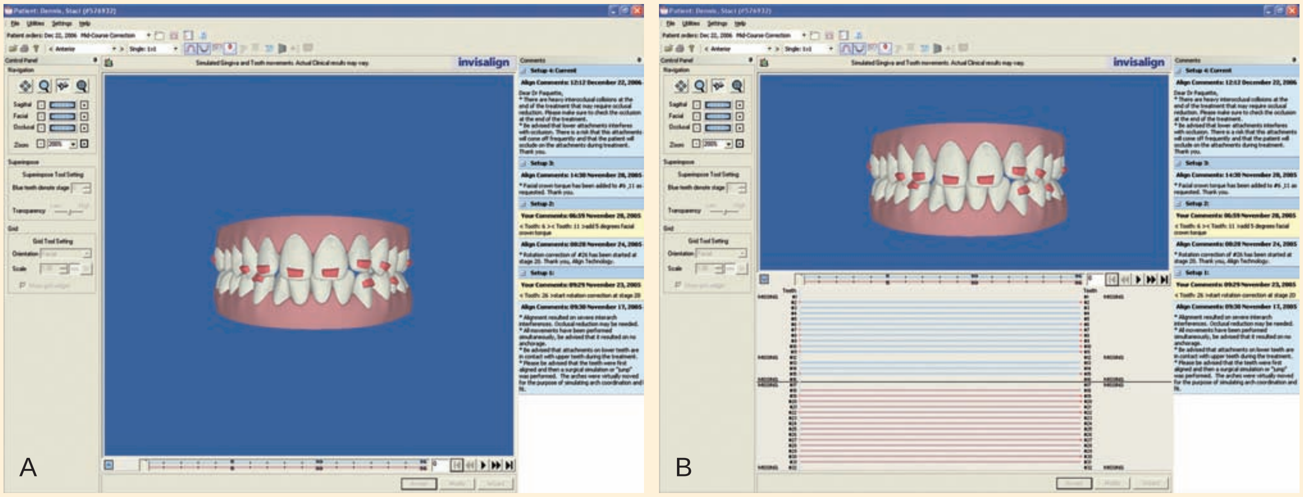


FIGURE 19-117 **A, B,** Final ClinCheck.

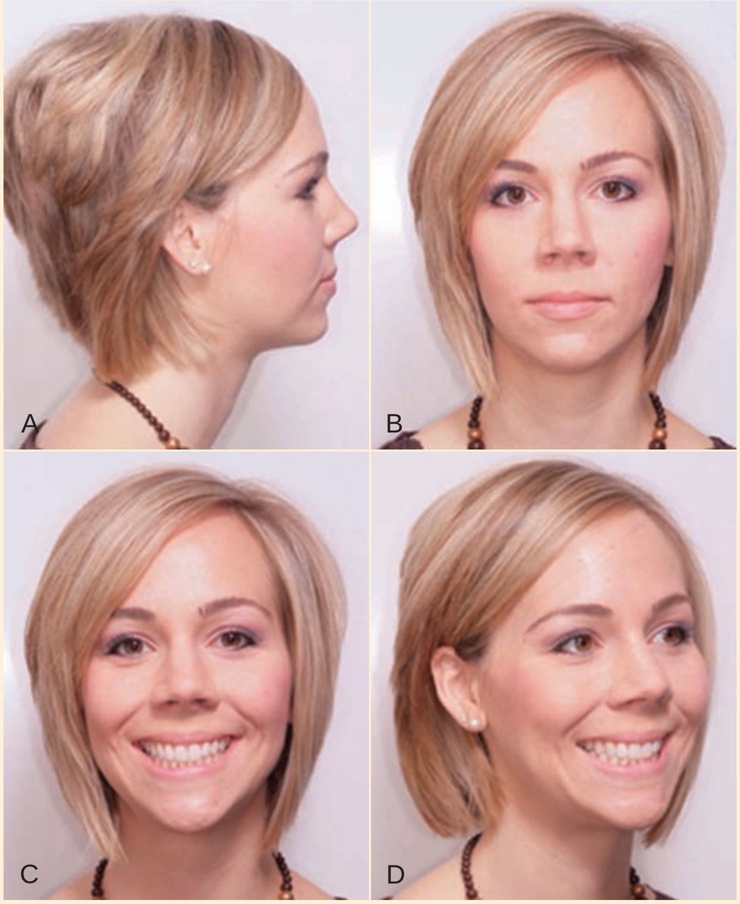


FIGURE 19-118 **A–J,** Placed fixed lower premolar to premolar.

CASE STUDY 19-5

CLASS II DIVISION 2—cont'd

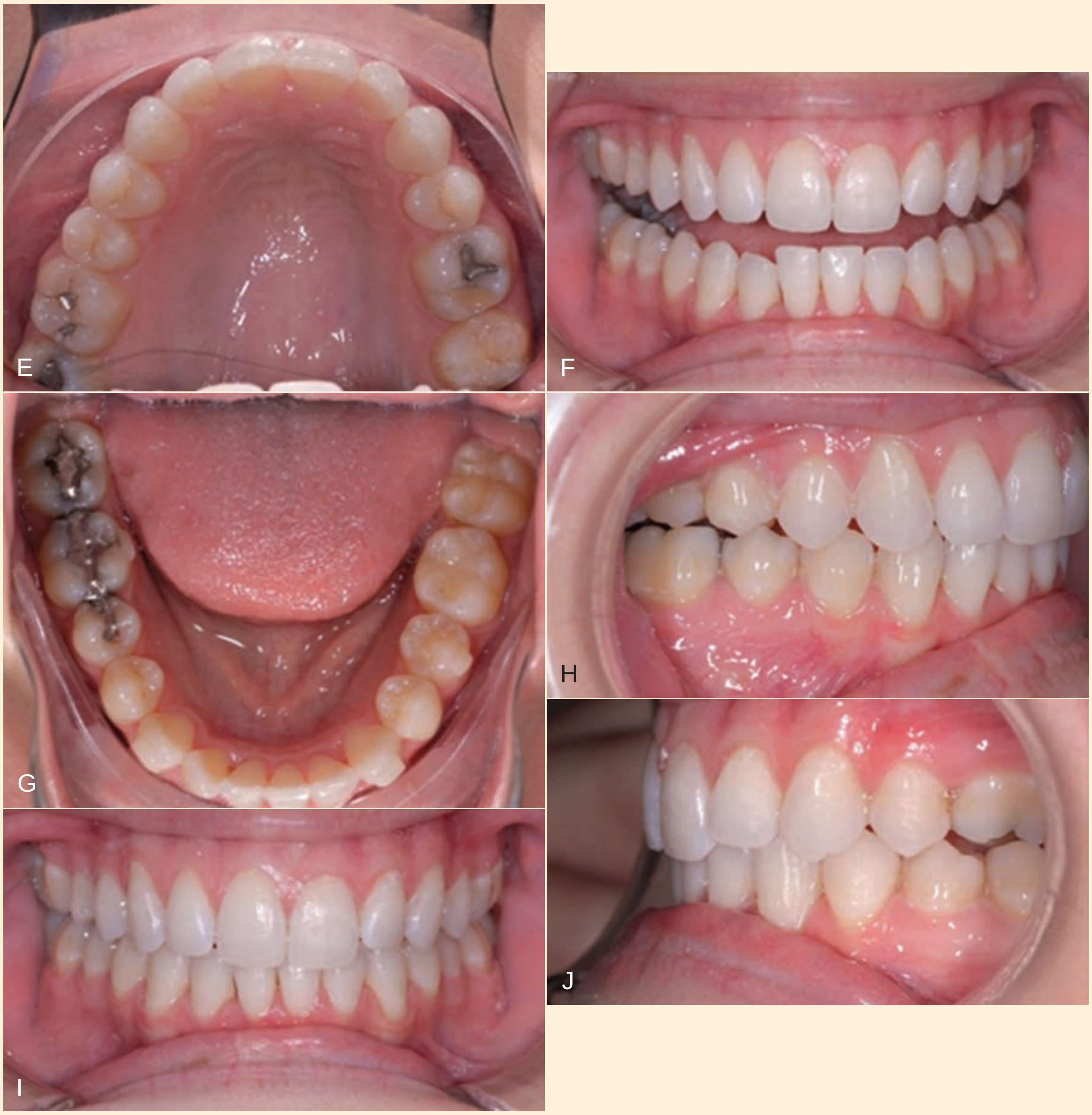


FIGURE 19-118, cont'd

Continued

CASE STUDY 19-5

CLASS II DIVISION 2—cont'd

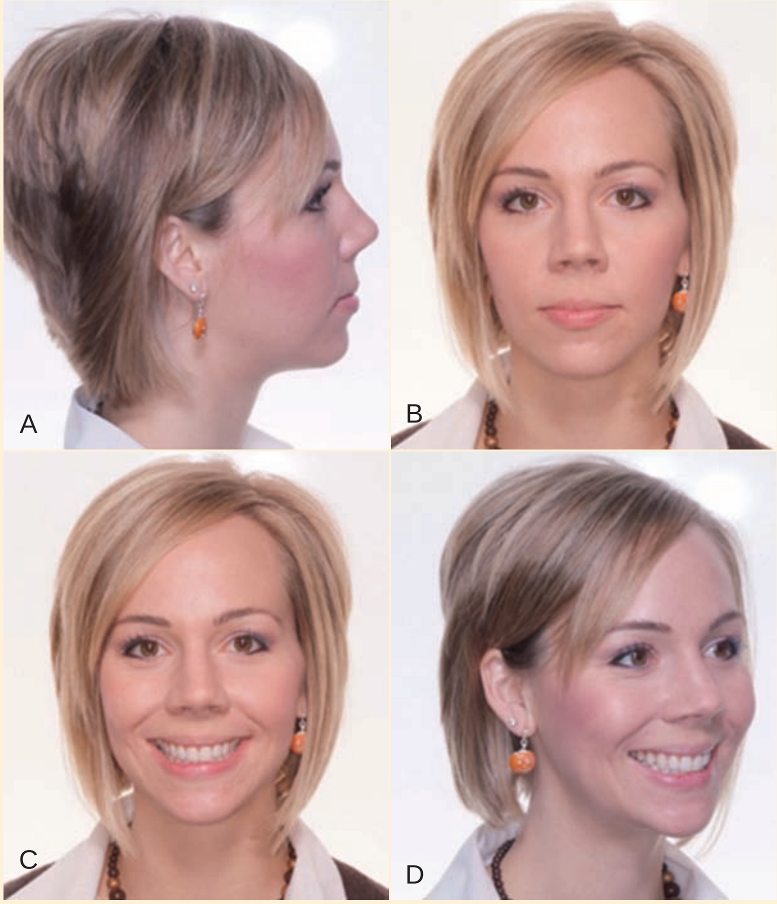


FIGURE 19-119 **A–J,** Final photographs.

CASE STUDY 19-5

CLASS II DIVISION 2—cont'd

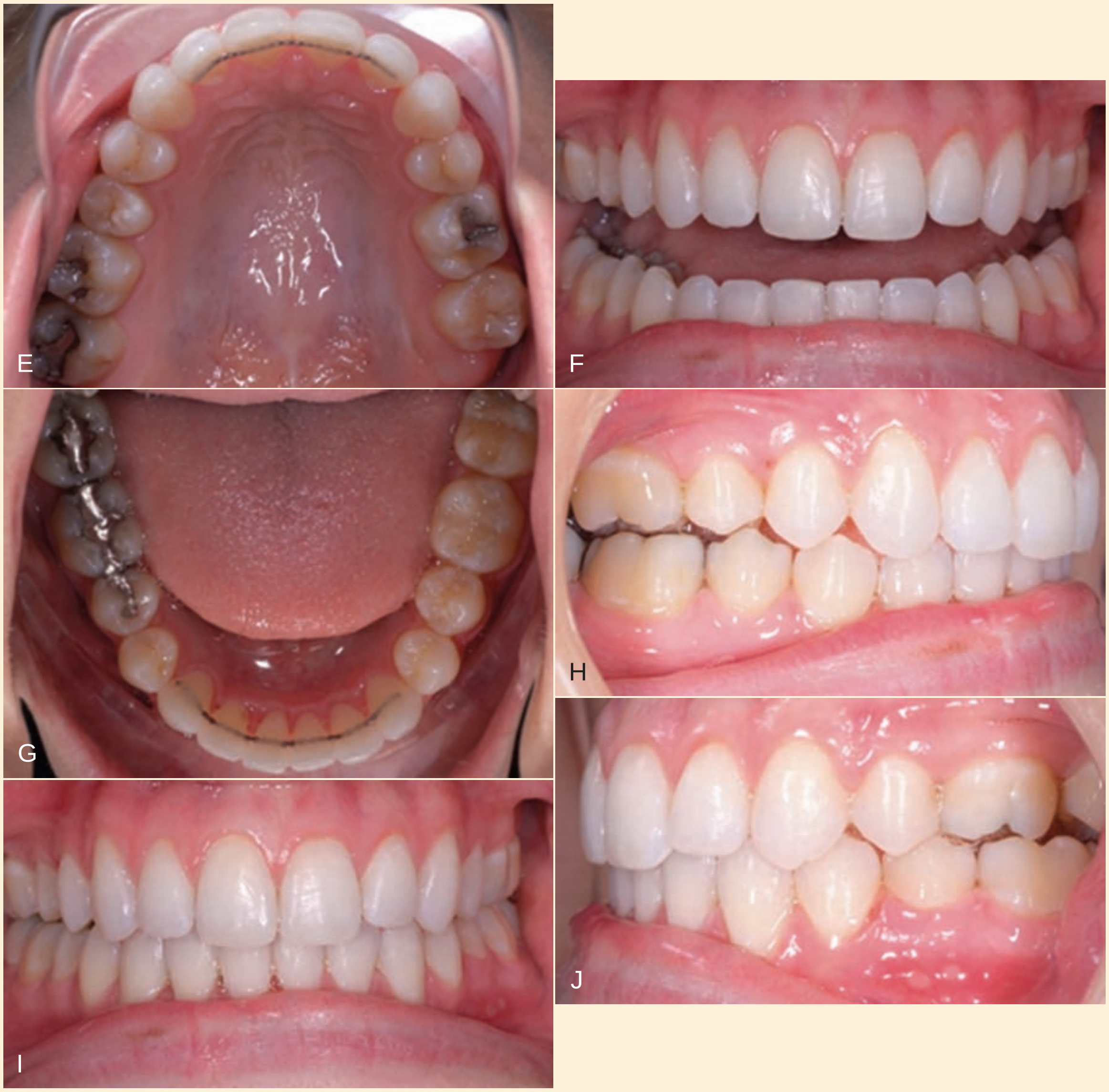


FIGURE 19-119, cont'd

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CHAPTER 20

Integrating Digital and Robotic Technologies:

Diagnosis, Treatment Planning, and Therapeutics

*Rohit C.L. Sachdeva**

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INTRODUCTION

The integration of digital technologies in diagnosis, treatment planning, appliance construction, and manipulation is changing the manner in which orthodontics is provided to patients. New opportunities for improved treatment coupled with shorter and more comfortable patient experiences are now available with these new paradigms. This chapter describes the practice of diagnostically driven robotic-assisted orthodontics (DDRA) using as the technology example SureSmile* technology. DDRA's foundation lies in a "patient-centered professional-based" care model. The goal of DDRA is to continuously improve treatment outcomes by providing targeted personalized care and minimizing variation in all aspects of care delivery and error proofing. Patient care is managed by applying sound principles grounded in conventional orthodontic treatment, using SureSmile's integrated digital technology platform, and applying unique diagnostic, care planning, and therapeutic strategies developed by the author. These strategies are enabled by capabilities that include three-dimensional (3D) imaging, a decision support system, and robotic-assisted archwire bending.[1–7]

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*SureSmile is a commercial suite of services of the OraMetrix Corporation. Dr. Sachdeva is the Co-founder and Chief Clinical Officer.

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THE CURRENT CRAFT-BASED CARE MODEL

The current practice of orthodontic care is “reactive.” It has historically been appliance driven and error prone. Error is seeded early in treatment as a result of a relatively cursory diagnosis and a limited treatment plan. The therapeutic strategy with the straight archwire approach to treatment relies on the “intelligence” built into the bracket prescription and its placement. In reality, great variation exists in the prescription of the brackets because of sloppy manufacturing practices. Furthermore, both direct and indirect bonding bracket placement procedures are fraught with errors driven by perceptual errors, lack of reliable global and local reference coordinates (because of differences in tooth morphology), and technique sensitivity. These sources of variations add to the error trap.

Initially, treatment begins with the objective of removing “noise” in the malocclusion through alignment and leveling through a replacement approach—for example, the use of a series of archwires that are progressively changed until a “working wire” is established. Transition to this archwire generally marks the beginning of the finishing stage of treatment. The choice of archwires and archform by a clinician is commonly based on “feel,” “clinical judgment,” “historical hangover,” or a “philosophical bent.” This approach to treatment adds another layer of complexity consisting of variation and error.

Finishing generally begins about a year into the care cycle. In reality, this is the “error correction” phase of treatment, which is managed very inefficiently through “reactive” processes. The doctor is challenged in managing issues arising from inadequate diagnosis and care planning, vagrancies in appliance prescription, and misapplication and mismanagement of therapeutic appliances, all at a time when patient compliance to treatment is at its lowest ebb (Figure 20-1, *A, B*).

This means that for all extant purposes, the patient is essentially placed into a doctor-devised orthodontic “intensive care unit” style of treatment where the doctor applies every conceivable therapeutic strategy at his or her disposal to “rescue” the patient. This can include bracket repositioning and or archwire modification through manual bending, reinforcement of greater patient compliance to wear elastics, or even reconsideration of treatment objectives.

This vicious cycle of “reactive” therapeutics is driven by the fact that the doctor lacks tools to validate the robustness of his or her decisions and has little assurance that the bracket repositions or the archwire bends are correct. As a result, the doctor awaits the patient’s next visit to assess treatment response to verify the soundness of his or her decisions and interventions made during the prior visit.

Unfortunately, the time dependency of this response adds another layer of complexity. A judgment has to be made as to when the next patient visit should be scheduled. Typically, at this point, the doctor resorts to following the patient at shorter intervals. The irony of this approach to managing care is that it triggers overuse of therapeutic interventions and invariably disrupts practice scheduling, jaundices the patient’s care experience, and negatively affects the patient’s lifestyle.

In summary, the current care model in managing orthodontic patients is “craft-based” and “doctor-centric.” It is driven by personal knowledge that is immune to clinical benchmarking and is therapeutically driven. Customization is hand-crafted, which increases the risk of vulnerability to both variation and error in care. Such treatment practices add to high internal costs, increase the care cycle, and place the patient at risk.

THE PATIENT-CENTERED AND PROFESSIONAL-BASED MODEL OF CARE

In “patient-centered, professional-based” care, patient safety should come first. The voice of the patient matters in all treatment decisions. “Professional-based care” is diagnostically driven, proactively managed, and evidence based. The doctor is system minded and manages care through streamlined processes and the use of appropriate technologies to minimize variation and deliver error-proof care. The doctor promotes a regenerative practice environment with continuous quality improvement initiatives. Finally, the professional caregiver is mindful of waste and seeks to lower internal costs and shorten the care cycle (Figure 20-2, *A–D*).

SURESMILE TECHNOLOGY AND ORAMETRIX DIGITAL LABORATORY

Technology

SureSmile is an integrated series of digital technologies and services solution that enables the orthodontist to practice a patient-centered, professional-based care model. The hardware technology includes a proprietary 3D image acquisition device called the OraScanner (Figure 20-3, *A*) and/or use of 3D cone beam computed tomography (CBCT) scans. SureSmile’s software solution provides a comprehensive set of utilities that help the practice manage the patient in both the physical and virtual world. The software provides tools such as (1) image management, (2) patient tracking, (3) workflow automation, (4) decision support, (5) prescriptive archwire design, (6) outcome evaluation, and (7) patient reports. These tools allow the doctor to diagnose, communicate, plan care, and design prescriptive customized orthodontic archwires (Figure 20-3, *B*).

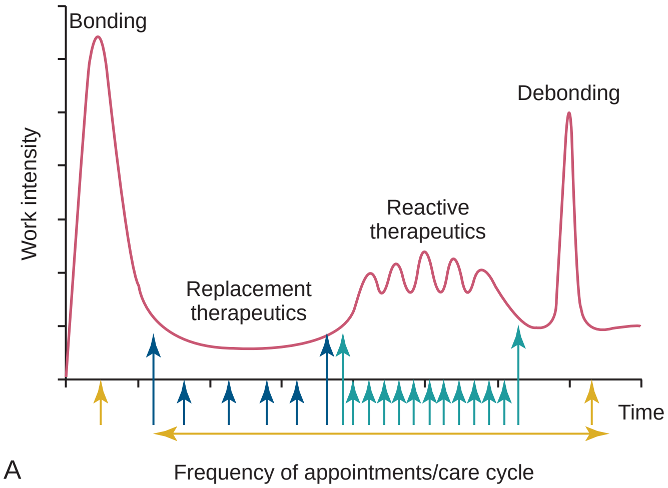
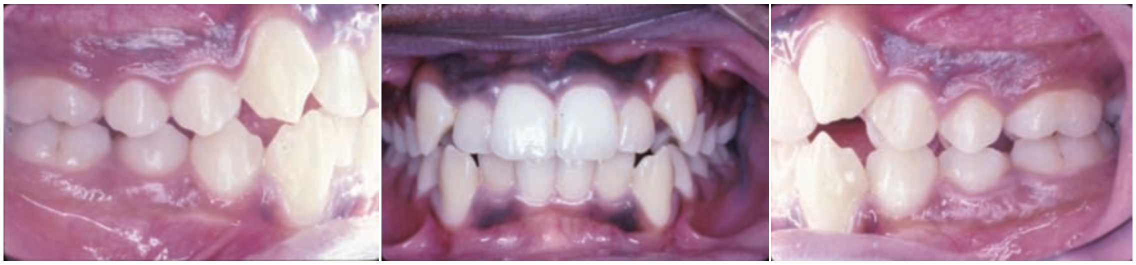
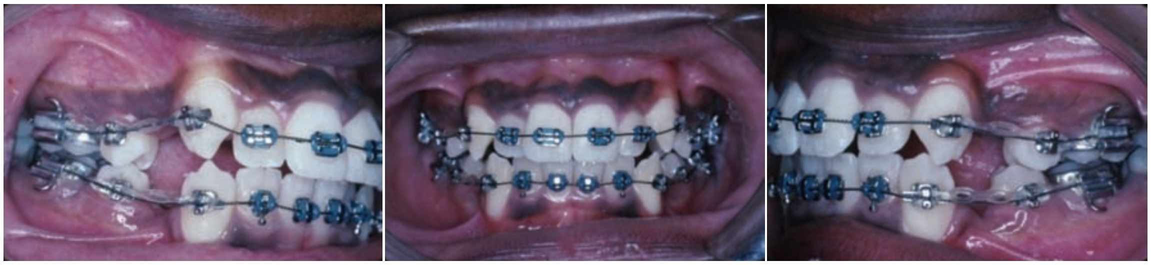


FIGURE 20-1 **A,** Craft-based care model in orthodontics. This stage begins with "Replacement" therapeutics followed by "Reactive" therapeutics, which is characterized by high work intensity and appointment density to correct for error. **B**, Finishing stage in orthodontics generally represents the error correction phase of treatment and commonly follows a "blunt end" path of error (i.e., errors are accumulated over time during the course of treatment).

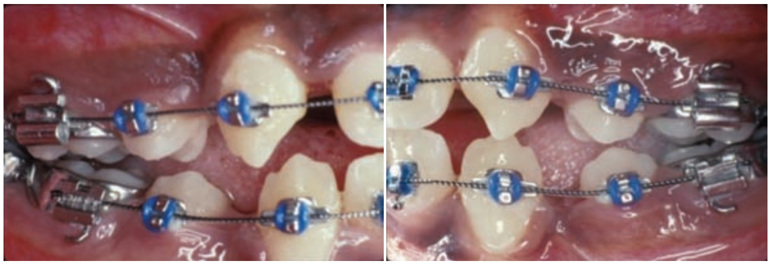
Error seeding



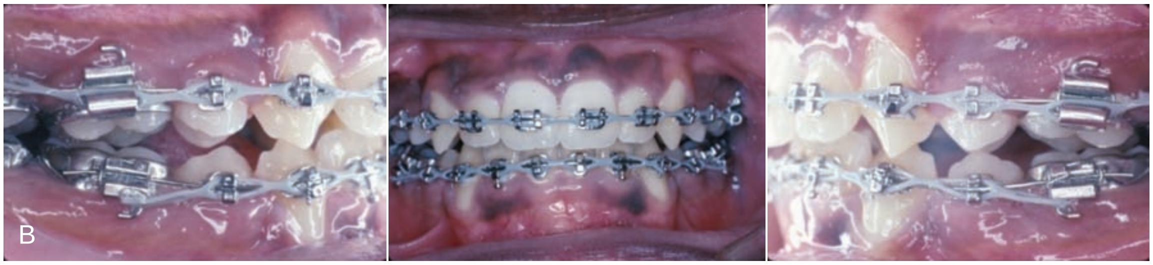
Error latency



Error recognition (micro aggregation)



Error recognition (macro aggregation)
- Finishing starts here
- Reactive correction



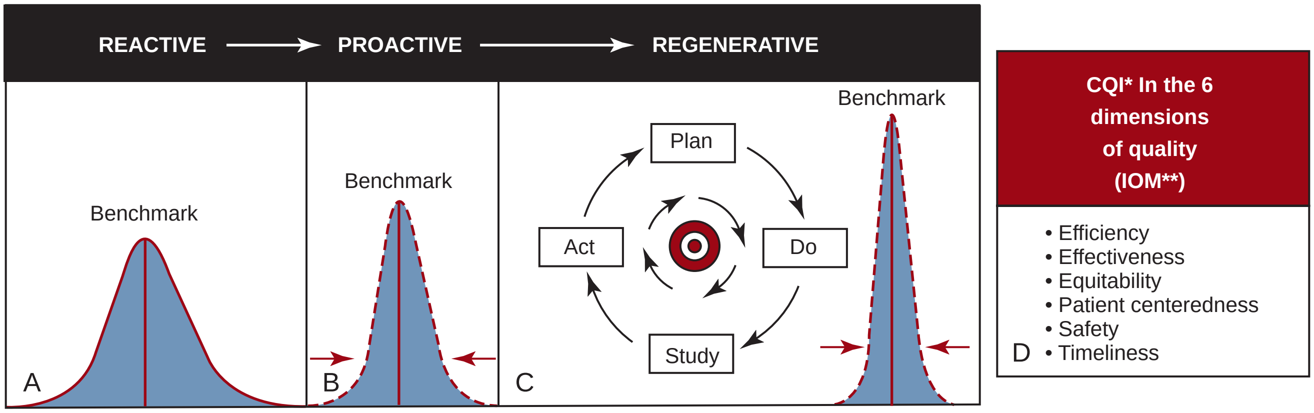


FIGURE 20-2 Practice models. **A,** Characterized by extreme variation. **B,** Characterized by active processes to reduce variation and error. **C, D,** Characterized by proactive management with continuous quality improvement (CQI*) initiatives with the goal of continuously improving the six dimensions of quality recommended by the Institute of Medicine (IOM**).

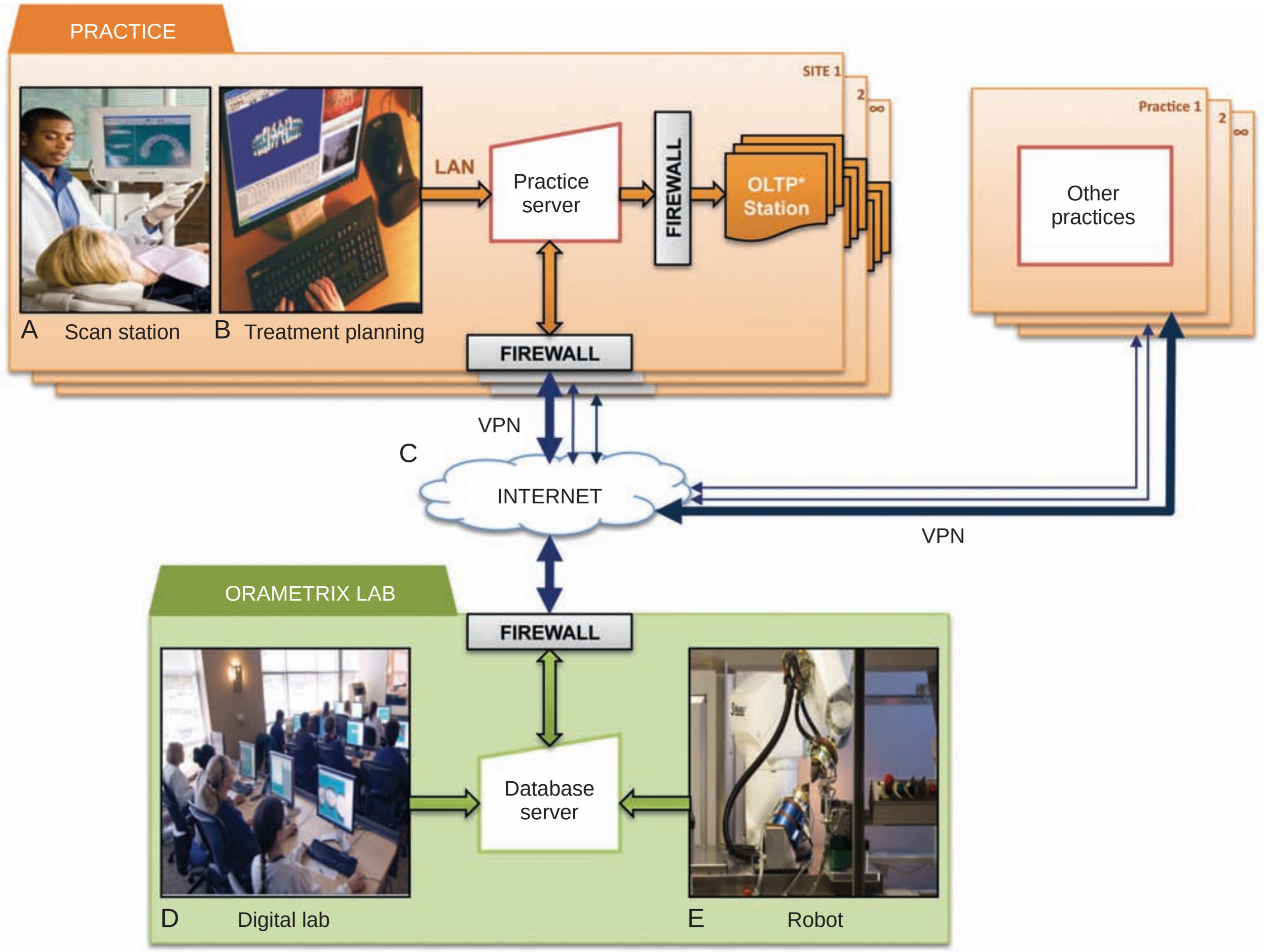


FIGURE 20-3 SureSmile Integrated Technology and Service Environment. **A,** OraScanner and work station. **B,** Treatment planning work node. **C,** Practice-laboratory connectivity. **D,** Remote laboratory. **E,** Six-axis robot.

Care in the digital environment with SureSmile is entirely managed in a workflow-process–driven environment. The orthodontist's care plan is used to create a target setup that in turn provides input parameters to drive a six-axis archwire-bending robot situated remotely from the practice (Figure 20-3, *E*). Materials such as copper-nickel-titanium (CuNiTi), beta titanium (TMA), Elgiloy (Rocky Mountain/Orthodontics, Denver, CO), and Azurloy (Ormco, Glendora, CA), comprising a range of cross sections (0.16-inch to 0.19- × 0.25-inch) and shapes (round, square, and rectangular), are bent by the robot to accomplish tooth movement prescribed by the orthodontist, with an angular and linear accuracy of 1 degree and 0.1 mm, respectively. Archwires can be for both labial and lingual techniques and for passive fixed retainers. Such versatility offers unlimited control to the doctor to achieve his or her treatment objectives. Furthermore, archwire design is not limited by bracket choice. The doctor is free to use any bracket system or prescription.

Orametrix Digital Laboratory and Manufacturing

The digital lab is remote to the practice and provides the practice with back office services. These include (1) modeling of all the 3D images (i.e., the diagnostic, therapeutic, and final models) and (2) creating the targeted setup based on a doctor's prescription. Bidirectional transfer of data between the practice and OraMetrix occurs through a designated practice server using a high-speed Internet connection such as DSL in a secure virtual private network. The customized archwires are fabricated in the manufacturing facilities associated with the laboratory and shipped to the practices on demand (Figure 20-3, *C, D*).

SURESMILE IN CLINICAL PRACTICE

This section provides the reader with an overview of the digital integration and process in a technologically advanced practice, described herein using SureSmile. SureSmile can be conveniently divided into three distinct phases as shown in Figure 20-4.

Pre–SureSmile Therapeutic Phase

The integration with the digital diagnosis and treatment planning starts with the consultation appointment and collation of a patient's diagnostic records. These include the patient's chief complaint and medical, dental, and orthodontic history. Records such as extraoral and intraoral photographs and cephalometric and panorex (or CBCT) radiographs and models are taken to supplement the clinical findings (Figure 20-5, *A–C*).

The orthodontist can create a digital diagnostic simulation (DDS) model to use for decision support during care planning. The DDS model is almost always created by scanning the rough pour of a patient's plaster model with the OraScanner. Scanning the model does not take more than 10 minutes and is done during downtime in the practice. Also, a direct in vivo CBCT scan of the patient can be processed to create the DDS model or a physical model scanned with CBCT. Digital models from other vendors such as OrthoCAD (Cadent, Fairview, NJ) in STL format can also be used and converted into SureSmile DDS models.

The scan of the models is electronically sent to the digital laboratory for modeling. The laboratory sets the global and bite registration of the model and separates each tooth into an individual object to allow simulations of individual teeth. The DDS model is electronically received by the practice within 5 business days (Figures 20-5 and 20-6).

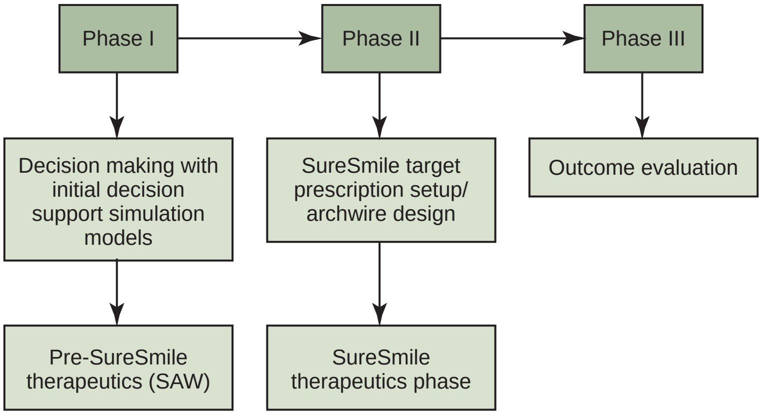

Phase I
Phase II
Phase III
Decision making with initial decision support simulation models
SureSmile target prescription setup/ archwire design
Outcome evaluation
Pre-SureSmile therapeutics (SAW)
SureSmile therapeutics phase

FIGURE 20-4 SureSmile workflow schema. Phase 1 is characterized by diagnosis, decision making and managing the patient with straight archwire (SAW) therapy. This is followed by Phase II where the custom setup and archwire are designed. The patient is managed with SureSmile targeted personalized archwires. Finally, in Phase III the treatment results are evaluated.

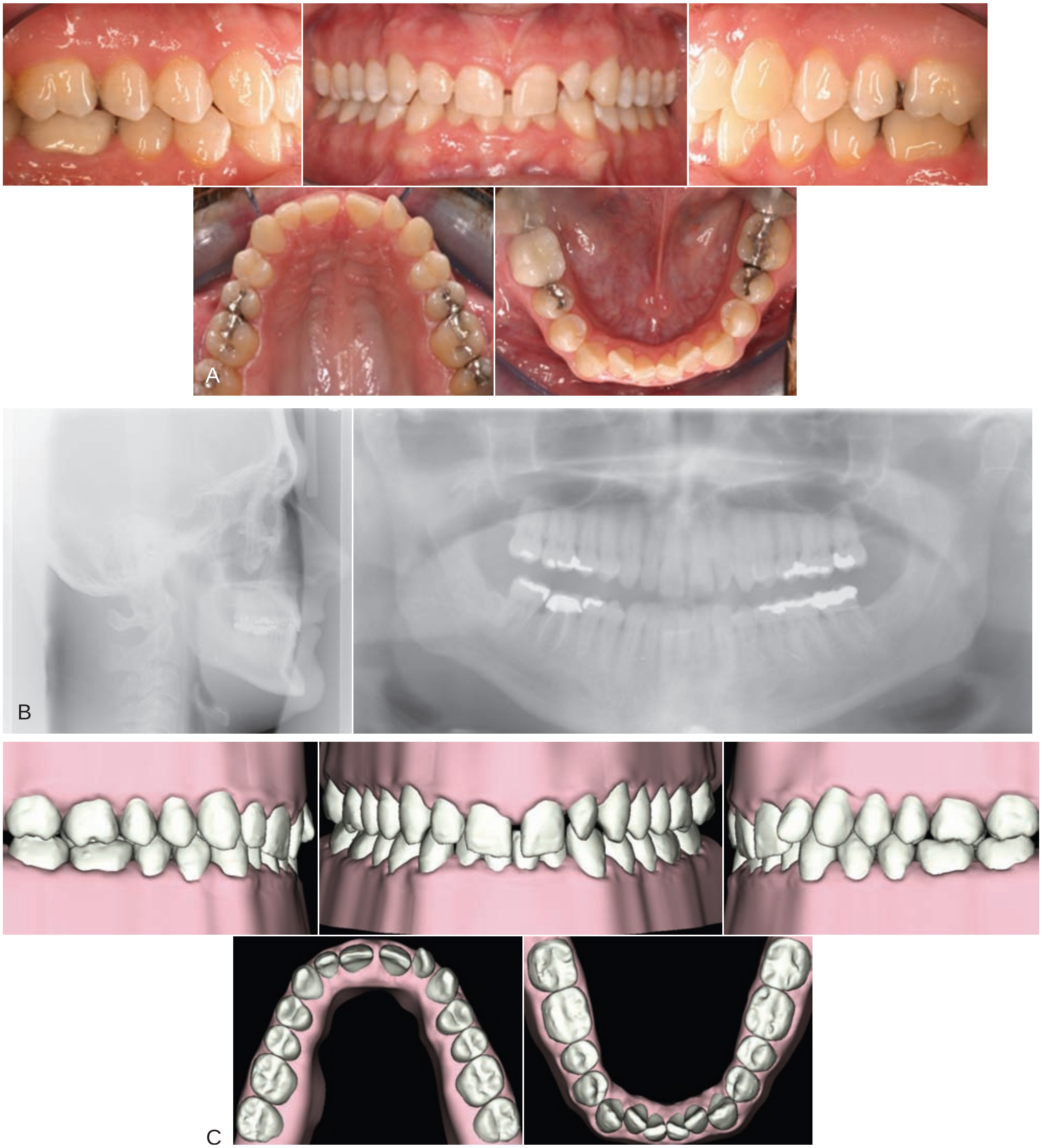


FIGURE 20-5 **A, B,** Initial SureSmile patient electronic record consists of a standard collage of the patient's two-dimensional images. **C,** Three-dimensional digital diagnostic simulation (DDS) model.

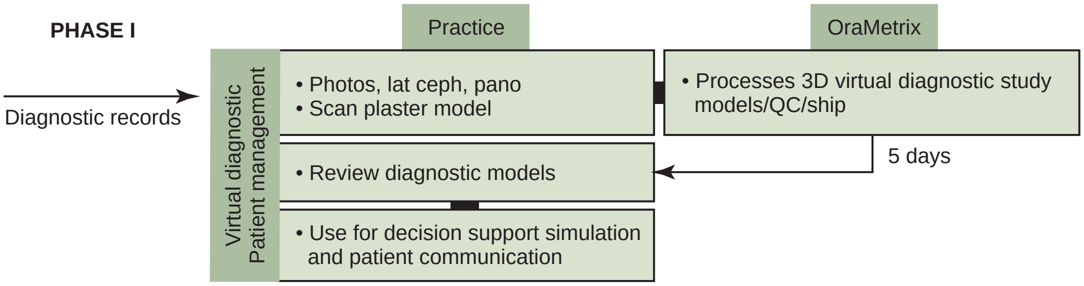

PHASE I
Practice
OraMetrix
Diagnostic records
Virtual diagnostic
Patient management
• Photos, lat ceph, pano
• Scan plaster model
• Processes 3D virtual diagnostic study models/QC/ship
5 days
• Review diagnostic models
• Use for decision support simulation and patient communication

FIGURE 20-6 Practice and laboratory work tasks and production time schedule in PHASE I.

The DDS model represents a virtual model of the patient's malocclusion with movable teeth (see Figure 20-7, *B*). The models can be used for 3D visualization and measurement; for example, the doctor can perform a Bolton analysis and a dynamic arch length inadequacy by affecting the boundary conditions and also measure discrepancy index. All these functions are automatically performed with the software (Figure 20-7, *A–D*).

Decision support with 3D simulation allows the doctor to validate his or her mental model of the patient's treatment plan. The doctor can rapidly simulate multiple treatment scenarios to establish proactive treatment strategies to achieve efficient and effective orthodontic treatment (Figure 20-7, *E–H*). The DDS model serves as an excellent interactive visual communication tool to discuss the patient's needs and treatment plan. Furthermore, consults can be given in a virtual environment with all stakeholders located remotely by using third-party, web-based collaborative tools such as GoToMeeting (www.gotomeeting.com).

The DDS model may also be used for planning strategic bracket placement. Once the initial plan is complete, therapy begins with a conventional straight archwire. There are a number of reasons for this. It allows treatment to begin immediately, and this is what patients usually desire. It fits well within the practice workflow, and some initial alignment of the teeth allows for easier insertion of the SureSmile archwires later, minimizing the risk of collisions in regions of severe crowding between the bends in the archwire and brackets. I plan my straight archwire mechanics with an objective of minimizing archwire replacement. I use additional therapeutic strategies such as constraint management and concurrent mechanics to help achieve more effective and efficient alignment and leveling with earlier torque control (Figure 20-8, *A*). These approaches are discussed in detail later. Generally speaking, for most types of malocclusions, the pre–SureSmile therapeutics phase does not exceed 6 months. However, with appropriate patient selection, an experienced doctor can start treatment with SureSmile customized archwire from the start of treatment or very soon thereafter. This requires following the fast track clinical pathway (Figure 20-9).

SureSmile Therapeutic Phase

The SureSmile "therapeutic" phase is triggered immediately after initial alignment and leveling have been achieved, and the intra-archform has been partially established. In a normal premolar extraction case, about 4 mm of extraction space should be closed prior to using SureSmile. Sagittal corrections can be done either prior to using SureSmile or concomitantly.

An in vivo scan is taken of the patient to capture the current 3D positions of the dentition and the brackets. This scan is called the "therapeutic" scan (see Figure 20-8, *B*). The SureSmile intraoral scanning device (i.e., OraScanner) or CBCT may be used to capture the "therapeutic" scan. The choice of using either of the technologies is determined by the doctor's preferences and abilities and the patient's needs.

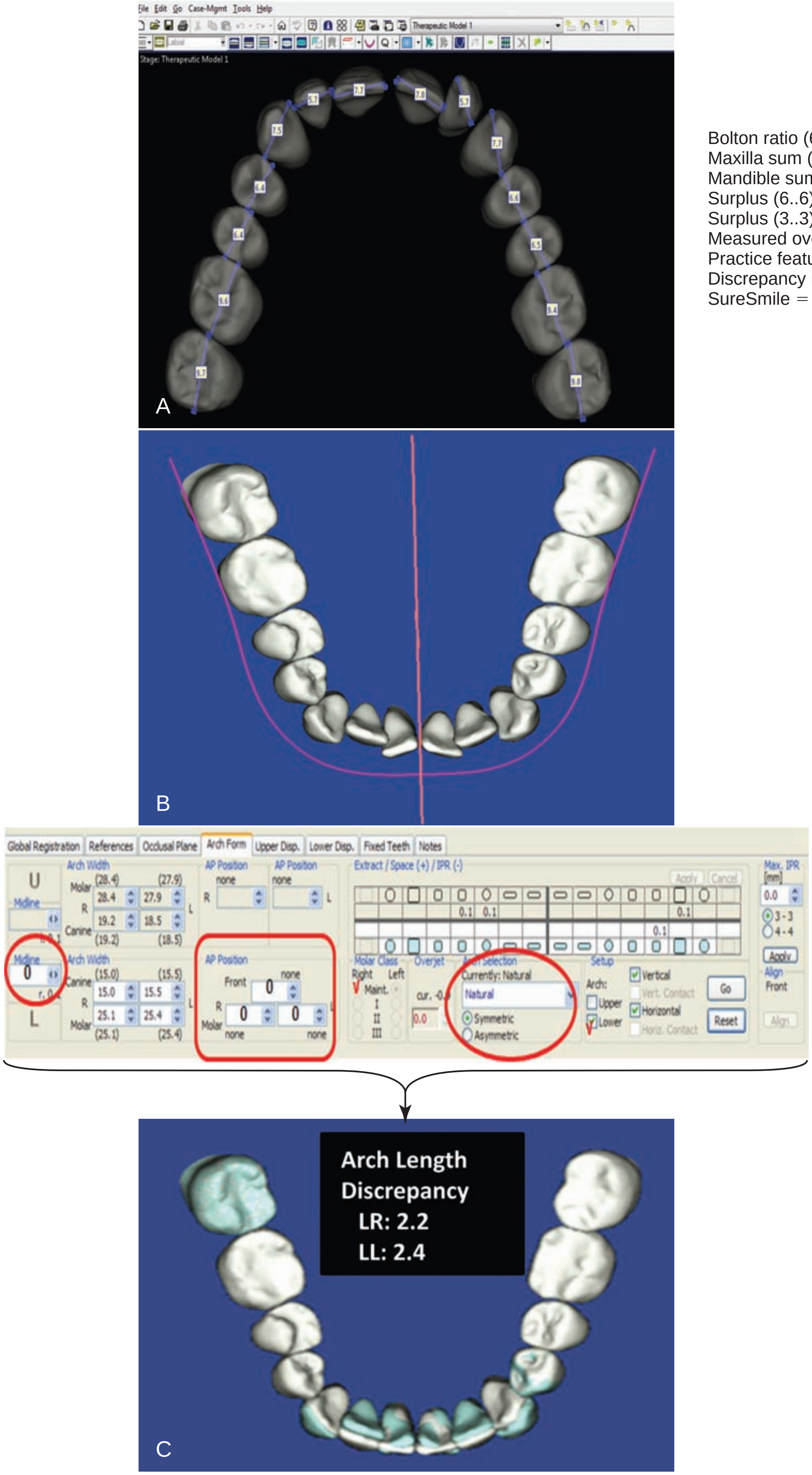
The OraScanner uses structured white light to capture the image of the dentition and therefore poses no radiation risk to the patient. Image capture with an OraScanner is not sensitive to patient motion. For experienced staff, it takes approximately 20 minutes to scan both the arches. An OraScanner does not capture root position but displays gingival tissue and has a higher resolution range of 30 to 50 microns (see Figure 20-8, *C*).

Image acquisition with CBCT takes less than 30 seconds at a voxel size of 0.2 mm and is very sensitive to patient motion. Furthermore, although the root's position can be captured, the gingival tissue cannot be visualized at this point. Large amalgams or porcelain fused to metal (PFM) crowns may cause artifacts through scatter. However, this can be handled by taking a partial OraScan of the teeth affected and stitching it to the rest of the CBCT image.

Once captured, the "therapeutic" scan is sent to the laboratory for postprocessing. The laboratory technician sets the global position and bite registration of the model. The teeth are separated to create individual objects. The captured bracket image on the "therapeutic" scan is matched against 3D bracket templates from the digital bracket library and the brackets are registered precisely on individual teeth in 3D space with an accuracy of 10 microns (see Figure 20-8, *D*). The "therapeutic" model is then electronically shipped to the practice (see Figure 20-8, *E*). The doctor evaluates the accuracy of this model, including the global orientation, and orders a "setup" prescription.

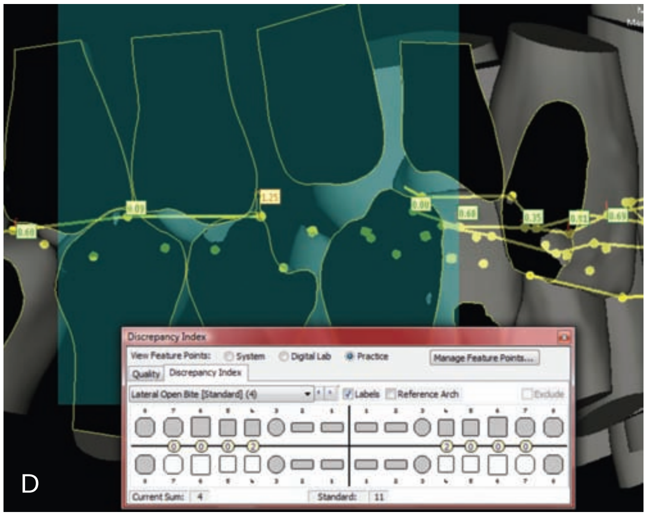
The doctor uses the "therapeutic" scan to evaluate treatment progress by best-fit registration on the diagnostic model and assess how the straight archwire has worked. The "therapeutic" model is used to establish the "setup prescription" (Figure 20-10). A number of approaches are used to provide this prescription; these include notes, a 3D quick simulation, or filling a prescription form. The choice is driven by the doctor's preference and consideration of the most effective way for the orthodontist to communicate with the laboratory technologists regarding the particular needs of the patient. Indeed, a combination of approaches is usually used.

The prescription is driven by considering six boundary conditions. The first letters of each of these boundary conditions form a memory mnemonic **MACROS**: (1) location of the **M**idline, (2) **A**rchform type, (3) **C**lass of occlusion, (4) choice of **R**eference teeth (i.e., the tooth positions that the doctor wishes to maintain), (5) **O**cclusal plane (commonly the aesthetic), and (6) **S**pecial instructions, which may include instructions such as the need for preferential spacing for restorative purposes, amount of interproximal reduction (IPR) permitted, and



Bolton ratio (6..6): 95.3 (3..3): 81.6
Maxilla sum (6..6): 87.1 mm (3..3): 42.1 mm
Mandible sum (6..6): 83.0 mm (3..3): 34.4 mm
Surplus (6..6): Lower 3.4 mm
Surplus (3..3): Lower 1.9 mm
Measured overjet: −0.3 mm
Practice feature points: read only
Discrepancy index: standard = 11
SureSmile = 6

FIGURE 20-7 **A,** Bolton analysis. **B,** Estimation of mandibular crowding. **C,** Boundary constraints set in the dialog box to evaluate dynamic arch length discrepancy.



Discrepancy Index

View Feature Points: ○ System ○ Digital Lab ● Practice

Manage Feature Points...

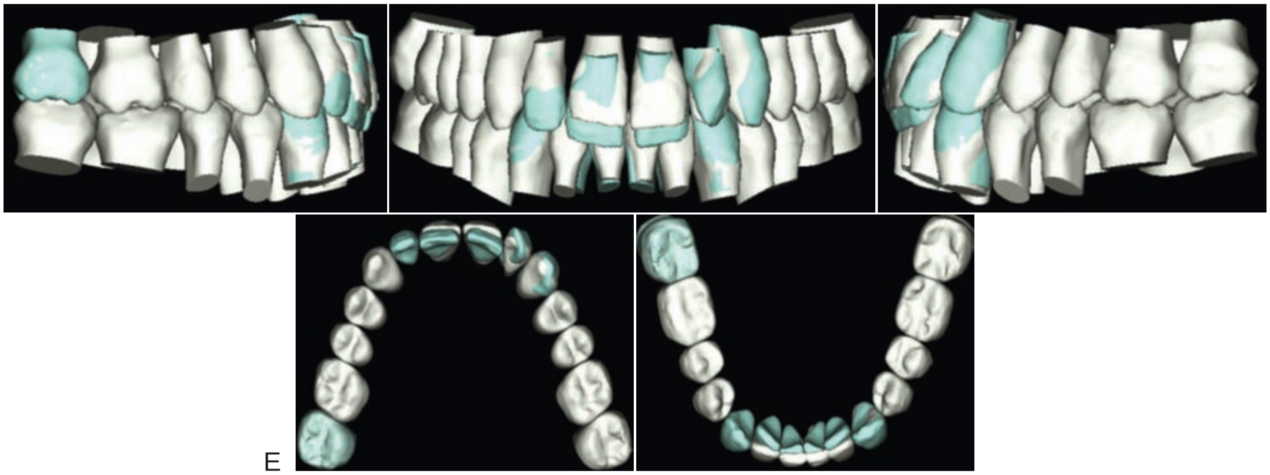
Quality | Discrepancy Index

Lateral Open Bite [Standard] (4)

☑ Labels ☐ Reference Arch ☐ Exclude

Current Sum: 4

Standard: 11



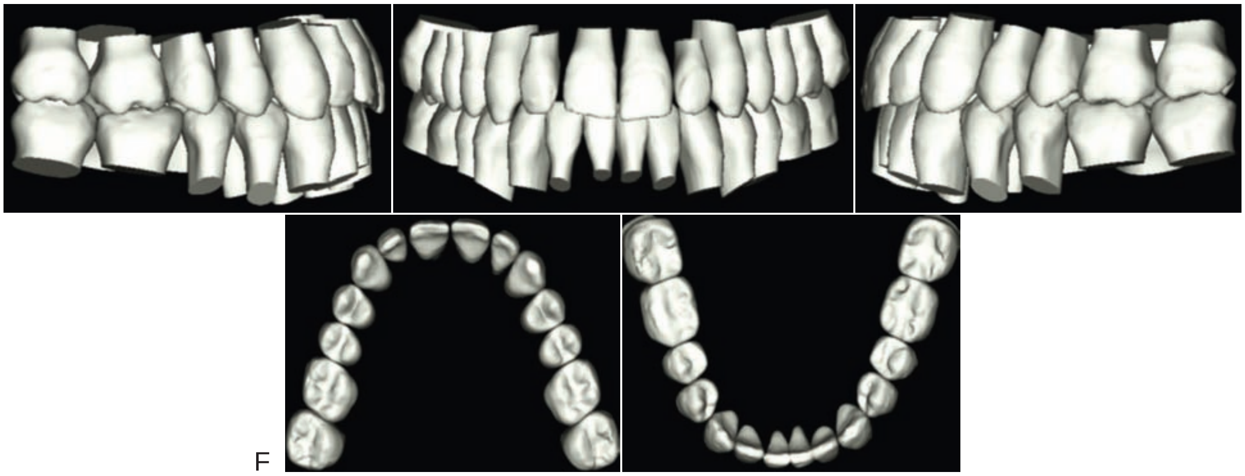


FIGURE 20-7, cont'd **D,** Discrepancy index is measured automatically. **E–H,** Decision support with simulation. The blue model represents the initial condition, and the white model, the simulation.

Continued

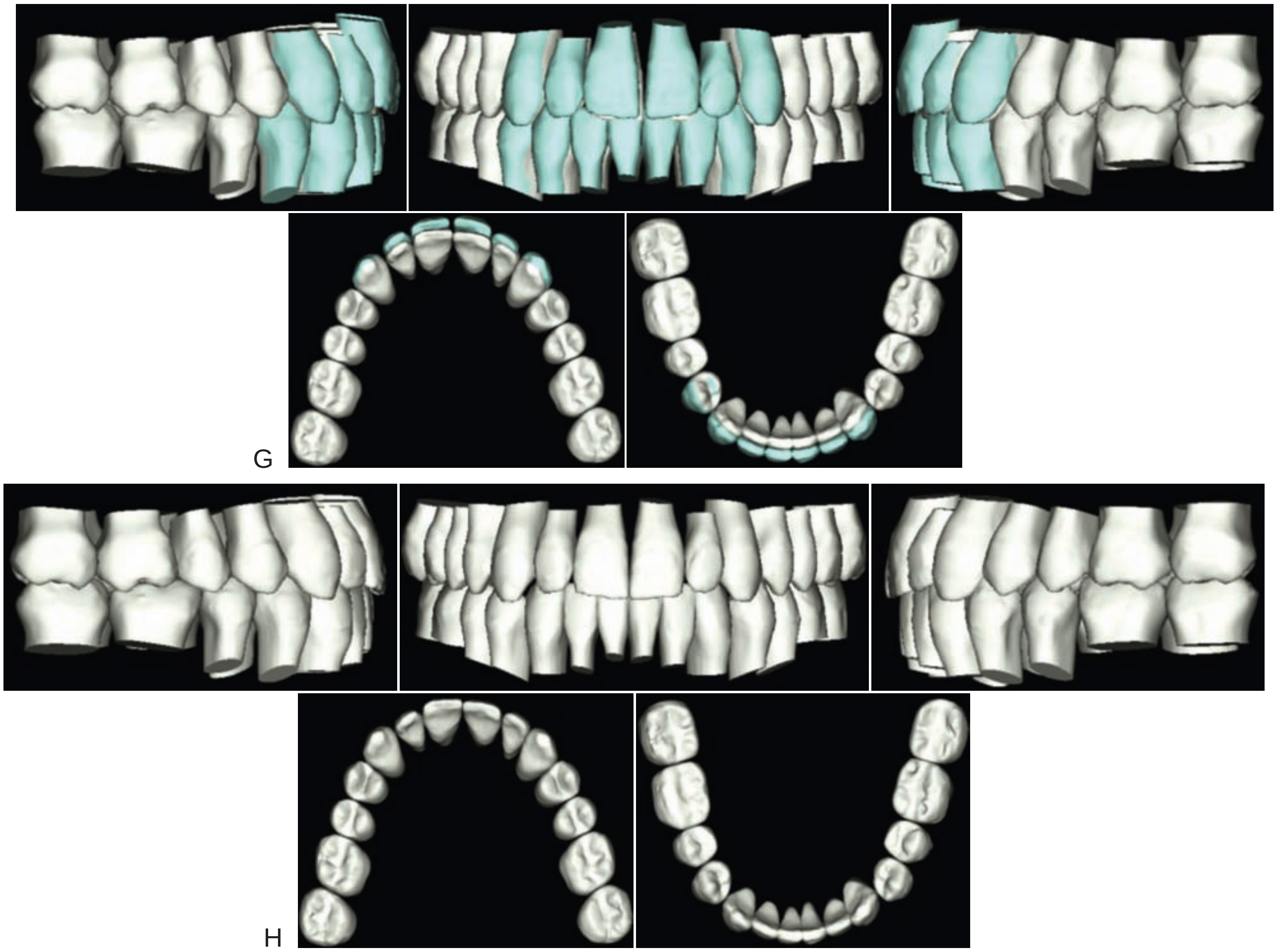


FIGURE 20-7, cont'd

so forth. Additionally, the doctor can set elastic boundaries to allow a range of tooth movements based upon a professional assessment of the anatomical constraints (see Figure 20-10).

The "setup" prescription is electronically submitted to the laboratory and the completed digital prescriptive "setup" is returned to the practice within 10 days. The doctor uses an editable checklist to evaluate the setup complimented with a grading/measuring system. This is critical to the success step in the management of the patient since the setup design directly affects the archwire prescription. The doctor can make or request the laboratory technologist to make changes in the setup (Figure 20-11, *A–D*).

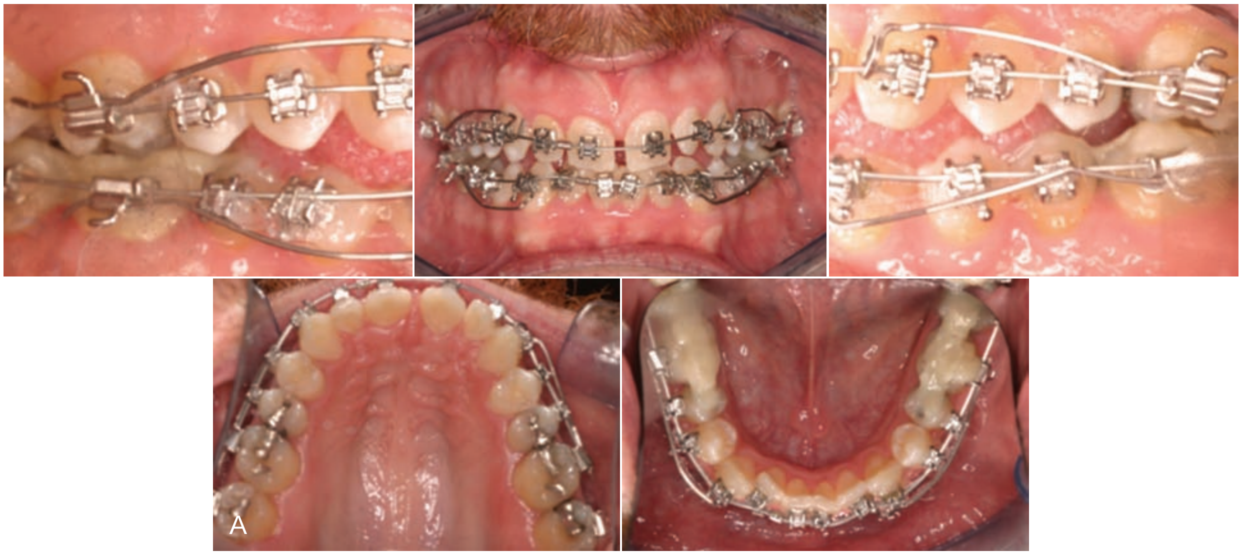
Tooth displacement with respect to the therapeutic "setup" and the working design of the prescriptive archwire is also evaluated (Figure 20-12, *A, B*).

Once the prescriptive "setup" is accepted, the doctor focuses on the archwire design. This includes design modifications such as setting limits of archwire expression and staging archwires, adding expansion or curve of Spee, overcorrection or limiting archwire bracket play by adding additional torque in the archwire, and choosing archwire material and cross section.

This capability offers the clinician a wealth of therapeutic strategies to control tooth movement. How these are used will be discussed later in greater detail in this chapter. Optimal archwire installation strategies can be simulated to minimize any archwire bend bracket collisions on insertion or during tooth movement. Modifications of archwire design in terms of location of wire bends can be also made to minimize this occurrence (Figure 20-13).

After submission of the archwire prescription, it takes 10 business days for the practice to receive the customized archwires. Prior to shipping, all archwires are scanned with a special laser scanner to measure the accuracy and precision of the archwire bends. Archwires are measured to an accuracy of 20 microns. This procedure is one of many steps instituted by the manufacturing facility to minimize errors in production through quality assurance and control.

Figure 20-14 shows a summary of Phase II practice—laboratory activity and timelines for product delivery. The customized wires are generally inserted within 6 weeks of taking the "therapeutic" scan. Instructions for insertion of archwires are provided, and the archwires are laser marked to minimize placement error. Patients



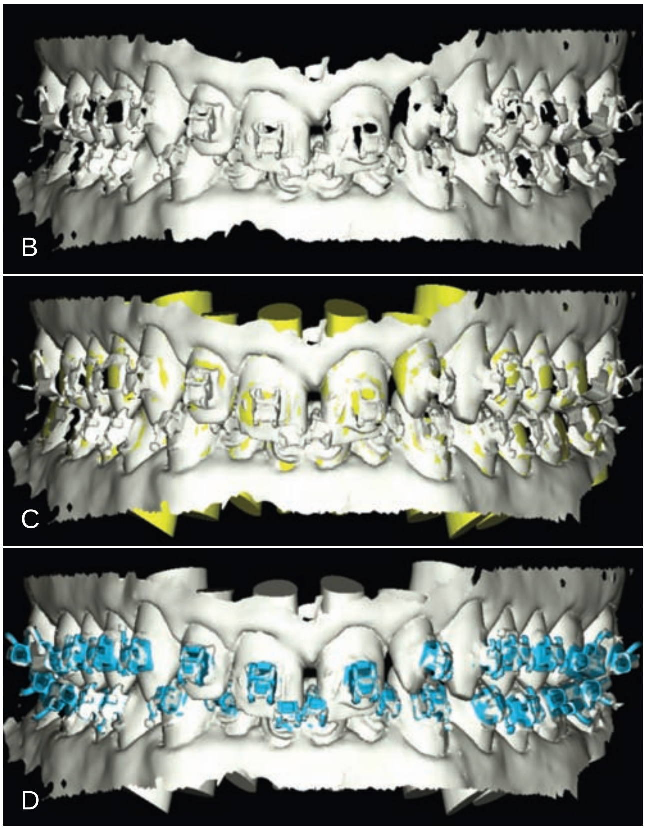
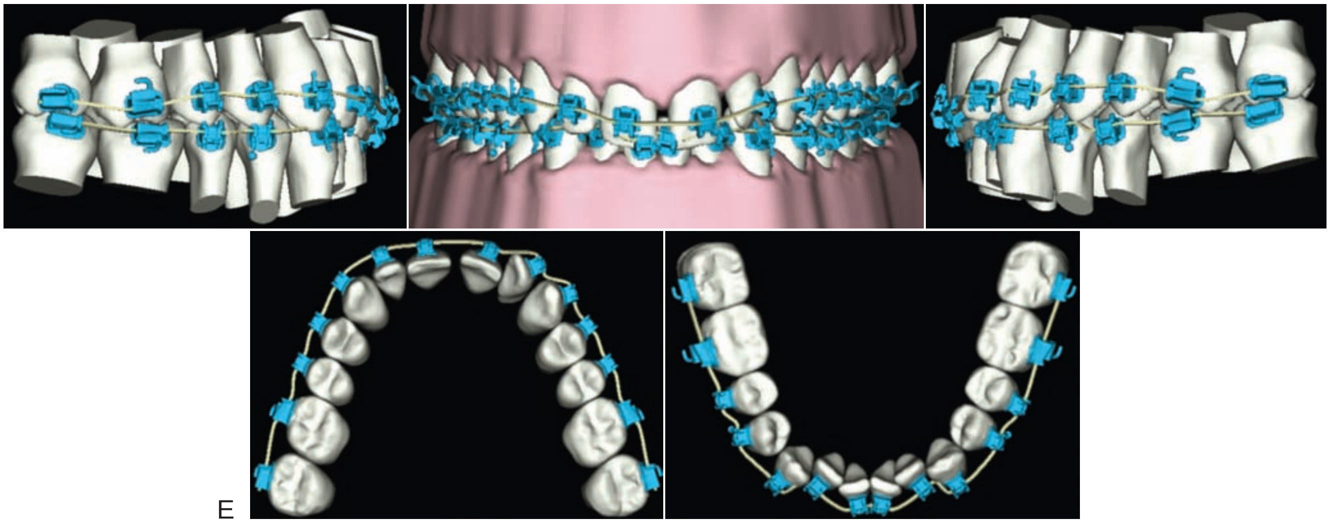


FIGURE 20-8 Intraoral images and corresponding therapeutic model. **A,** Initial pre–SureSmile therapeutics 17- × 25-inch CuNiTi A_F 35°C, 17- × 25-inch TMA tip back springs to help arch leveling and posterior bite turbos to prevent interarch tooth collisions. **B,** Therapeutic raw scan data. **C,** Raw scan with tooth template used for "void" filling. **D,** Bracket registration on raw scan. **E,** The therapeutic model shows the tooth and bracket position at the time of scan; also, the state of archwire deactivation can be displayed.



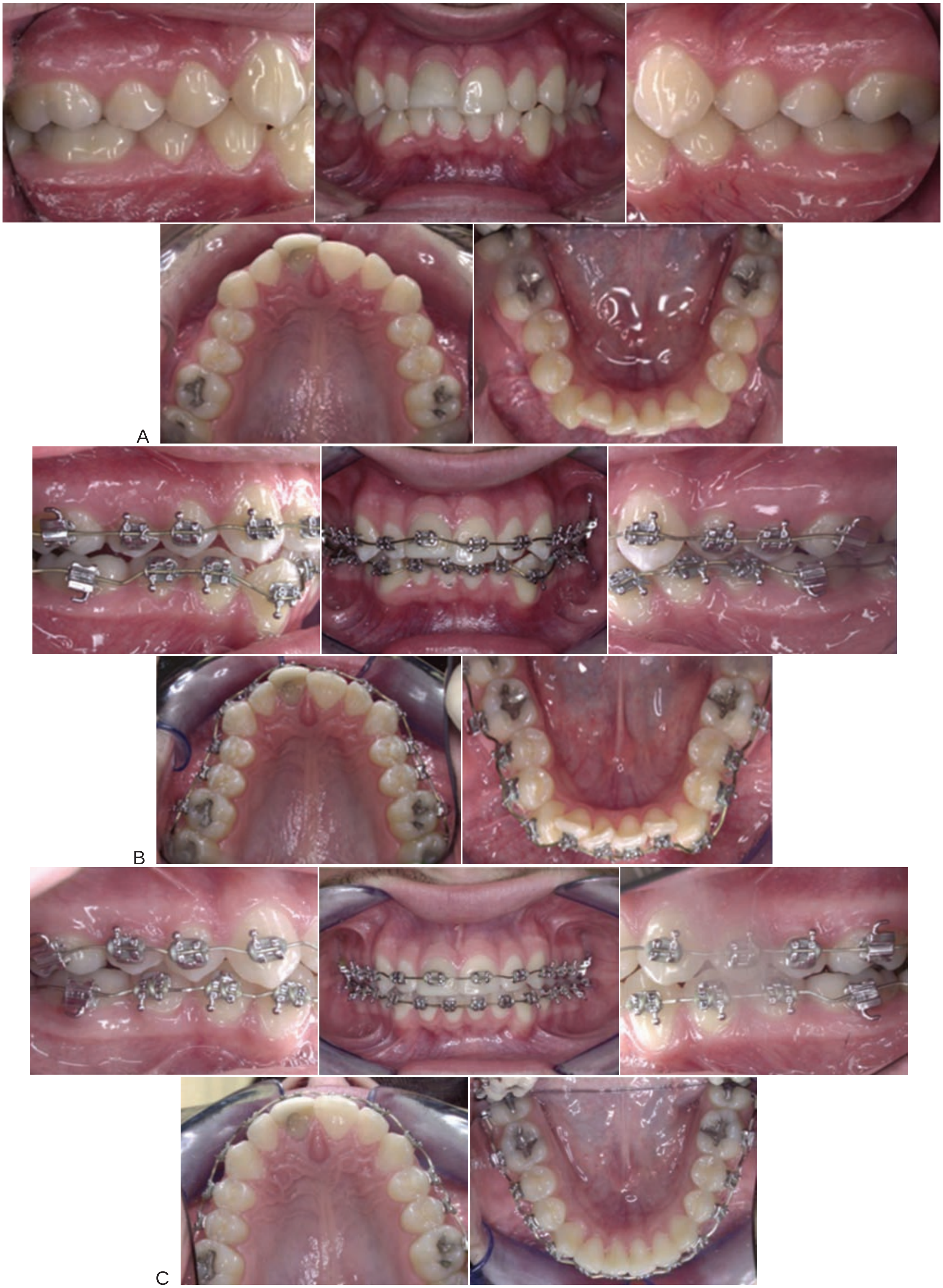


FIGURE 20-9 **A–D,** Full expression archwires (100%). In this patient, a full expression 17- × 25-inch CuNiTi 35°C archwire was used from the beginning (9/24/02) to the end of treatment (8/15/03). This is an example of a fast-track clinical pathway.

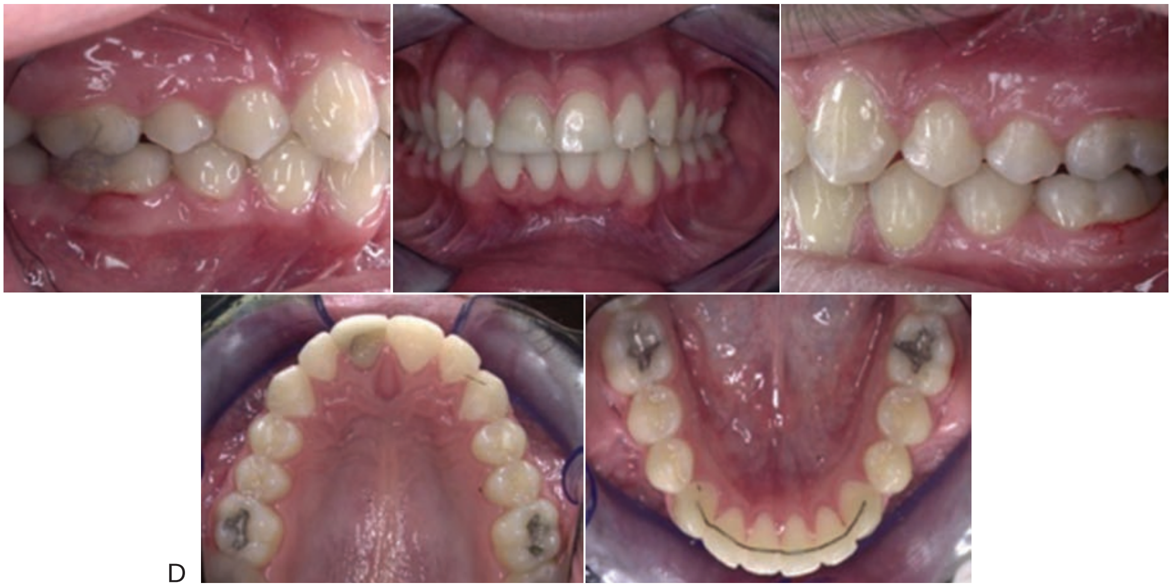
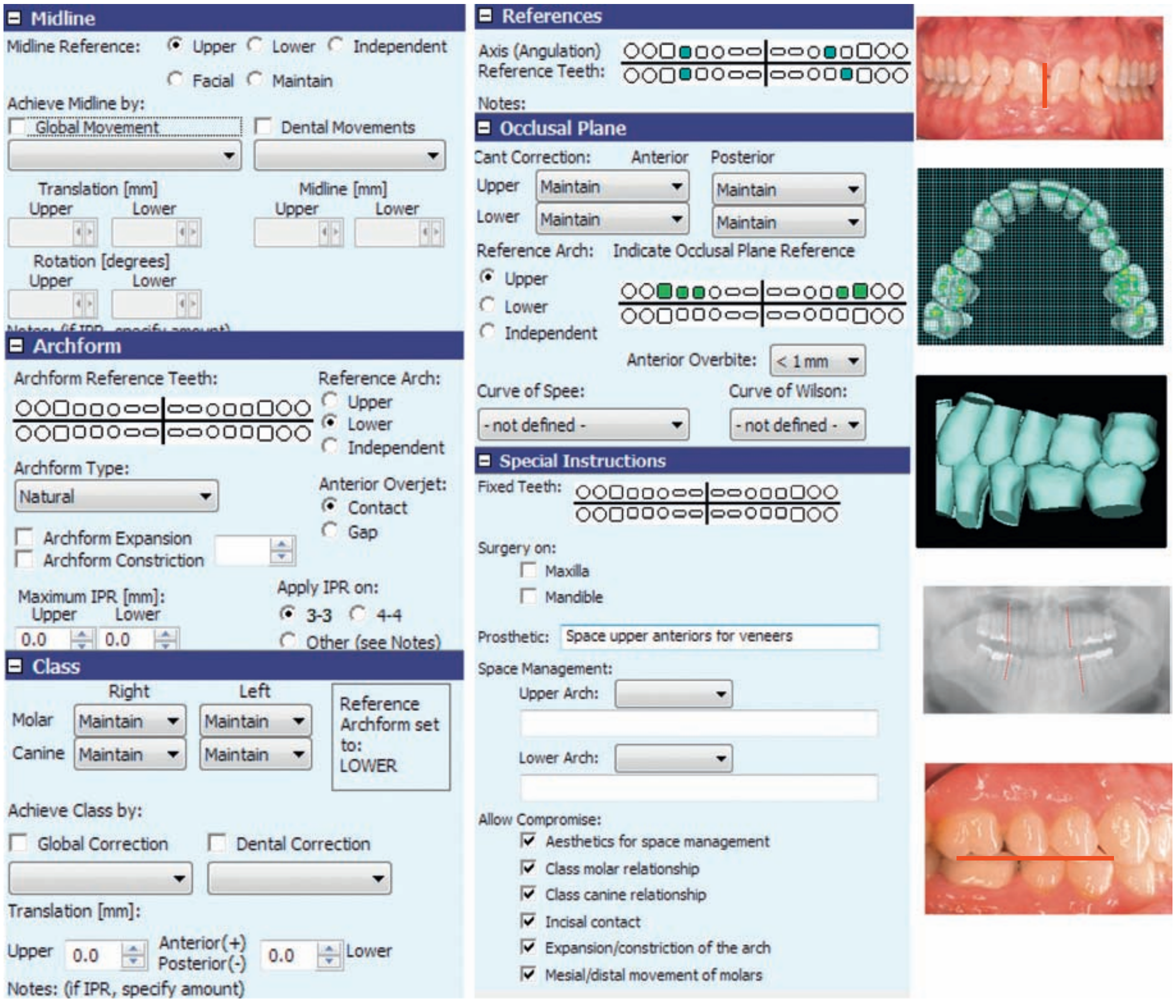


FIGURE 20-9, cont'd



Midline

Midline Reference: ● Upper ○ Lower ○ Independent ○ Facial ○ Maintain

Achieve Midline by:

☐ Global Movement ☐ Dental Movements

Translation [mm] Upper Lower

Midline [mm] Upper Lower

Rotation [degrees] Upper Lower

Archform

Archform Reference Teeth:

Reference Arch: ○ Upper ● Lower ○ Independent

Archform Type: Natural

☐ Archform Expansion

☐ Archform Constriction

Anterior Overjet: ● Contact ○ Gap

Maximum IPR [mm]: Upper 0.0 Lower 0.0

Apply IPR on: ● 3-3 ○ 4-4 ○ Other (see Notes)

Class

	Right	Left
Molar	Maintain	Maintain
Canine	Maintain	Maintain

Reference Archform set to: LOWER

Achieve Class by:

☐ Global Correction ☐ Dental Correction

Translation [mm]:

Upper 0.0 Anterior(+) Posterior(-) 0.0 Lower

Notes: (if IPR, specify amount)

References

Axis (Angulation) Reference Teeth:

Notes:

Occlusal Plane

Cant Correction:	Anterior	Posterior
Upper	Maintain	Maintain
Lower	Maintain	Maintain

Reference Arch: ● Upper ○ Lower ○ Independent

Indicate Occlusal Plane Reference

Anterior Overbite: < 1 mm

Curve of Spee: - not defined -

Curve of Wilson: - not defined -

Special Instructions

Fixed Teeth:

Surgery on:
- ☐ Maxilla
- ☐ Mandible

Prosthetic: Space upper anteriors for veneers

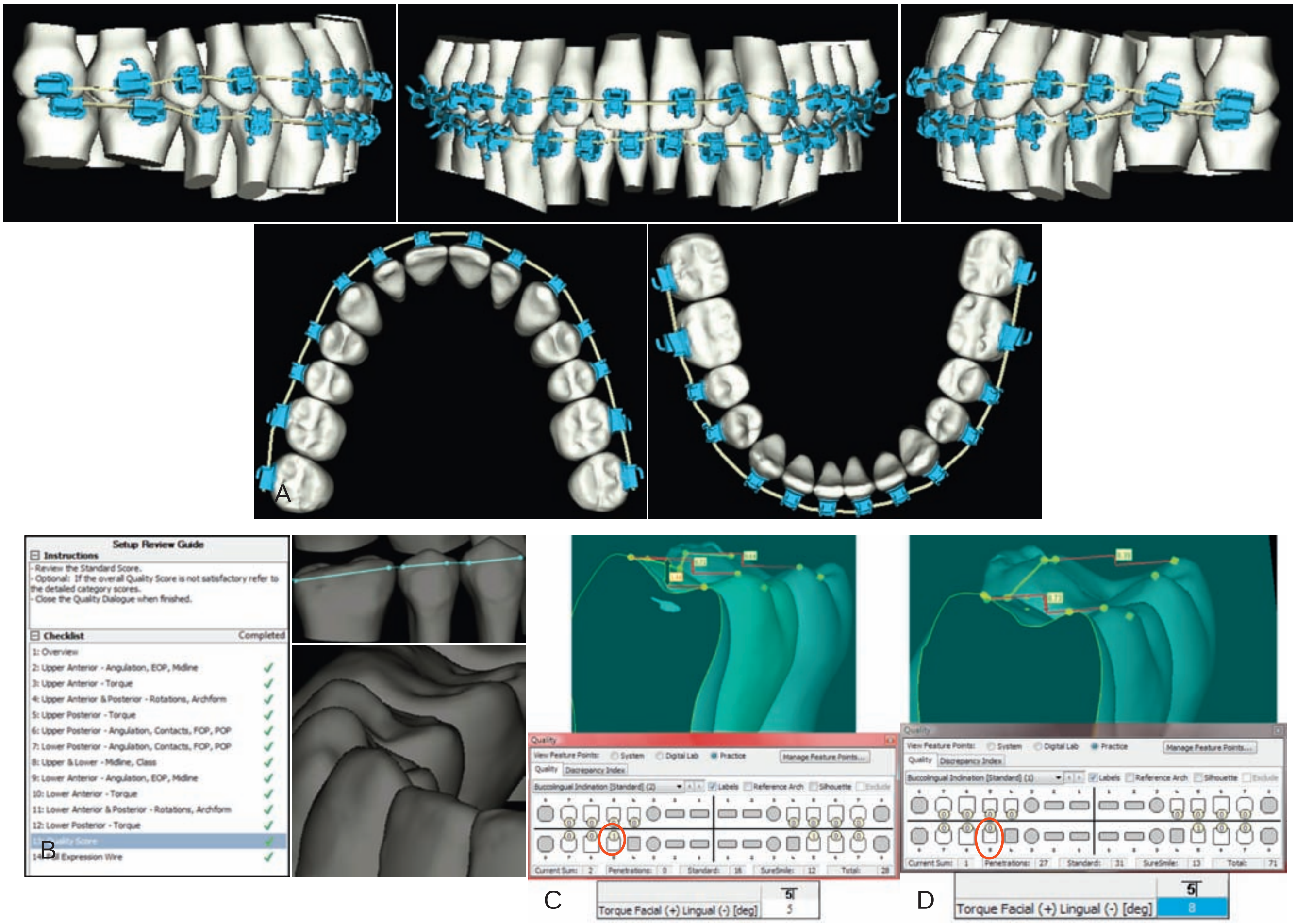
Space Management:

Upper Arch:

Lower Arch:

Allow Compromise:
- ☑ Aesthetics for space management
- ☑ Class molar relationship
- ☑ Class canine relationship
- ☑ Incisal contact
- ☑ Expansion/constriction of the arch
- ☑ Mesial/distal movement of molars

FIGURE 20-10 Electronic prescription form. The doctor fills the form using a workflow-driven checklist using MACROS and can also set elastic boundary preferences (i.e., range of acceptable treatment limits).



Setup Review Guide

⊟ Instructions

- Review the Standard Score.
- Optional: If the overall Quality Score is not satisfactory refer to the detailed category scores.
- Close the Quality Dialogue when finished.

⊟ Checklist	Completed
1: Overview	
2: Upper Anterior - Angulation, EOP, Midline	✓
3: Upper Anterior - Torque	✓
4: Upper Anterior & Posterior - Rotations, Archform	✓
5: Upper Posterior - Torque	✓
6: Upper Posterior - Angulation, Contacts, FOP, POP	✓
7: Lower Posterior - Angulation, Contacts, FOP, POP	✓
8: Upper & Lower - Midline, Class	✓
9: Lower Anterior - Angulation, EOP, Midline	✓
10: Lower Anterior - Torque	✓
11: Lower Anterior & Posterior - Rotations, Archform	✓
12: Lower Posterior - Torque	✓
13: Quality Score	✓
14: Full Expression Wire	✓

A
B
C
Torque Facial (+) Lingual (-) [deg]
5
D
Torque Facial (+) Lingual (-) [deg]
8

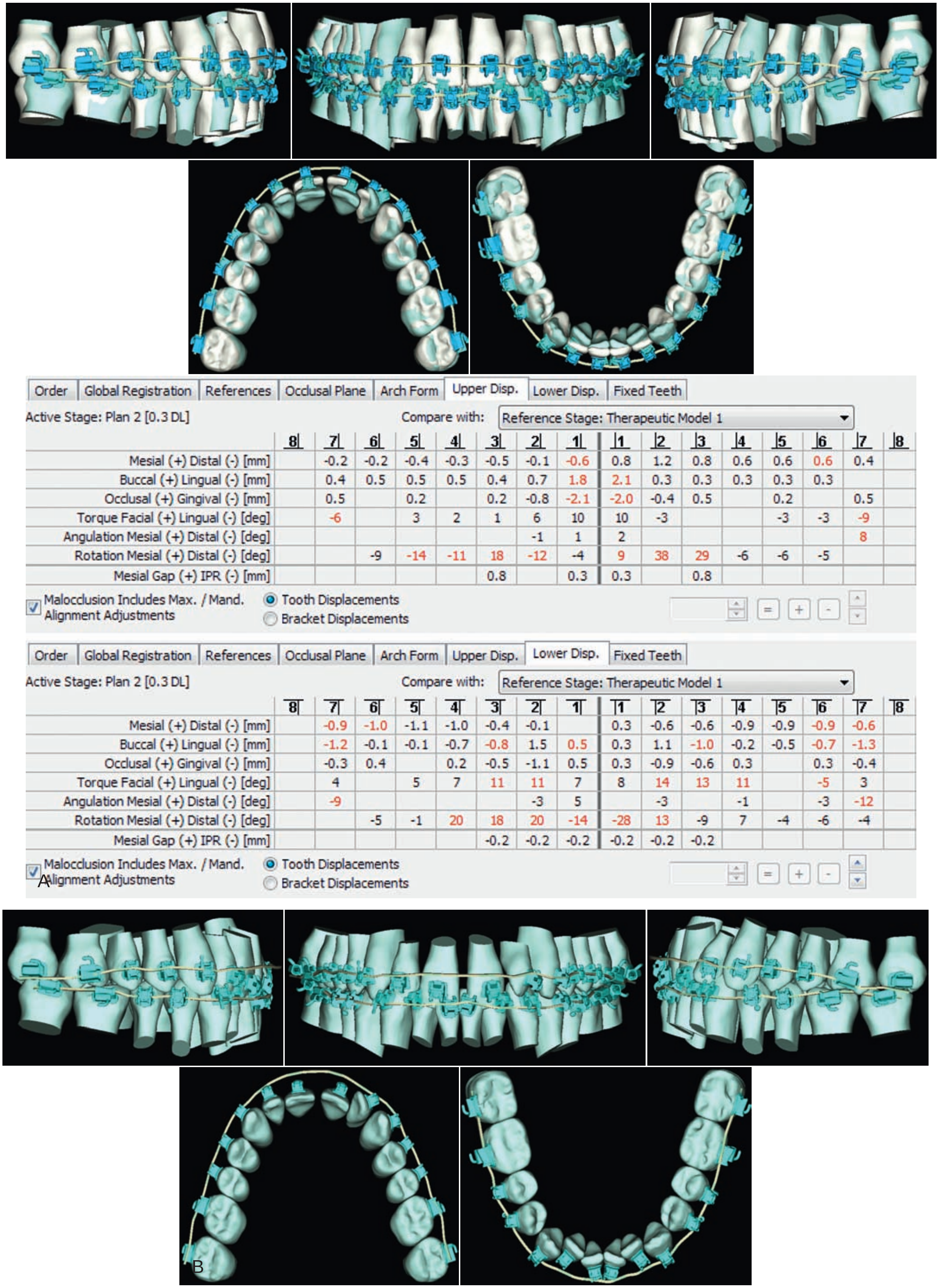
FIGURE 20-11 **A,** Target "setup" based upon the doctor's prescription. **B,** Practice-based checklist. **C–D,** Measuring/grading tools to evaluate "setup". Modifications can be made at practice site.

are commonly seen after 8 weeks post custom-designed wire insertion (Figure 20-15).

At this visit, the doctor and the staff use a guided checklist to evaluate the progress of care. Using a checklist helps prevent any oversights during the evaluation process. By the 16th week, if the target occlusion has not been reached, the doctor may use a second level of support checklists and a guided therapeutic archwire modification schema to manage corrections. Archwire modifications may be accomplished at the chairside with the "virtual plier." This is a "numeric guided" approach. Here the doctor best estimates the needed prescription and enters it into the archwire modification field. Then he or she uses a simulation to see if his estimated correction is reasonable. Typically, a second set of prescription archwires with minor local modifications is required to achieve desirable outcomes. This commonly occurs because of a "miss" during the evaluation of the setup that just escaped the eye or at times because of constraints between the teeth not being managed appropriately and resulting in spurious tooth movement.

There is great assurance in using the robot-assisted modified archwires since bends in areas requiring no modifications are maintained. This is extremely difficult, if not impossible, to do with conventional archwires since their repeated removal, modification, and insertion deform the archwire and commonly lead to breakage. Replicating the geometry of the broken archwire is frustrating and usually cannot be accomplished. Modified archwires are shipped within 10 days of receipt of the prescription. Also, if needed, the doctor may order a "backup" pair of bendable prescriptive archwires made from TMA or Azuroly in advance and make minor modifications at the chairside. This is accomplished by making the appropriate corrections on a "working" setup model and using the automatically generated archwire template as a guide to make the adjustments.

Generally speaking, most treatment with SureSmile prescription archwires is completed within a period of 6 months. Clinical judgment and the image of the target setup with the final position of the brackets "on" are used to gauge whether the prescriptive archwire has "worked out" and the treatment goals are achieved.



Order | Global Registration | References | Occlusal Plane | Arch Form | Upper Disp. | Lower Disp. | Fixed Teeth

Active Stage: Plan 2 [0.3 DL]

Compare with: Reference Stage: Therapeutic Model 1

	8⌋	7⌋	6⌋	5⌋	4⌋	3⌋	2⌋	1⌋	⌊1	⌊2	⌊3	⌊4	⌊5	⌊6	⌊7	⌊8
Mesial (+) Distal (-) [mm]		-0.2	-0.2	-0.4	-0.3	-0.5	-0.1	-0.6	0.8	1.2	0.8	0.6	0.6	0.6	0.4	
Buccal (+) Lingual (-) [mm]		0.4	0.5	0.5	0.5	0.4	0.7	1.8	2.1	0.3	0.3	0.3	0.3	0.3		
Occlusal (+) Gingival (-) [mm]		0.5		0.2		0.2	-0.8	-2.1	-2.0	-0.4	0.5		0.2		0.5	
Torque Facial (+) Lingual (-) [deg]		-6		3	2	1	6	10	10	-3			-3	-3	-9	
Angulation Mesial (+) Distal (-) [deg]							-1	1	2						8	
Rotation Mesial (+) Distal (-) [deg]			-9	-14	-11	18	-12	-4	9	38	29	-6	-6	-5		
Mesial Gap (+) IPR (-) [mm]						0.8		0.3	0.3		0.8					

☑ Malocclusion Includes Max. / Mand. Alignment Adjustments

● Tooth Displacements

○ Bracket Displacements

Order | Global Registration | References | Occlusal Plane | Arch Form | Upper Disp. | Lower Disp. | Fixed Teeth

Active Stage: Plan 2 [0.3 DL]

Compare with: Reference Stage: Therapeutic Model 1

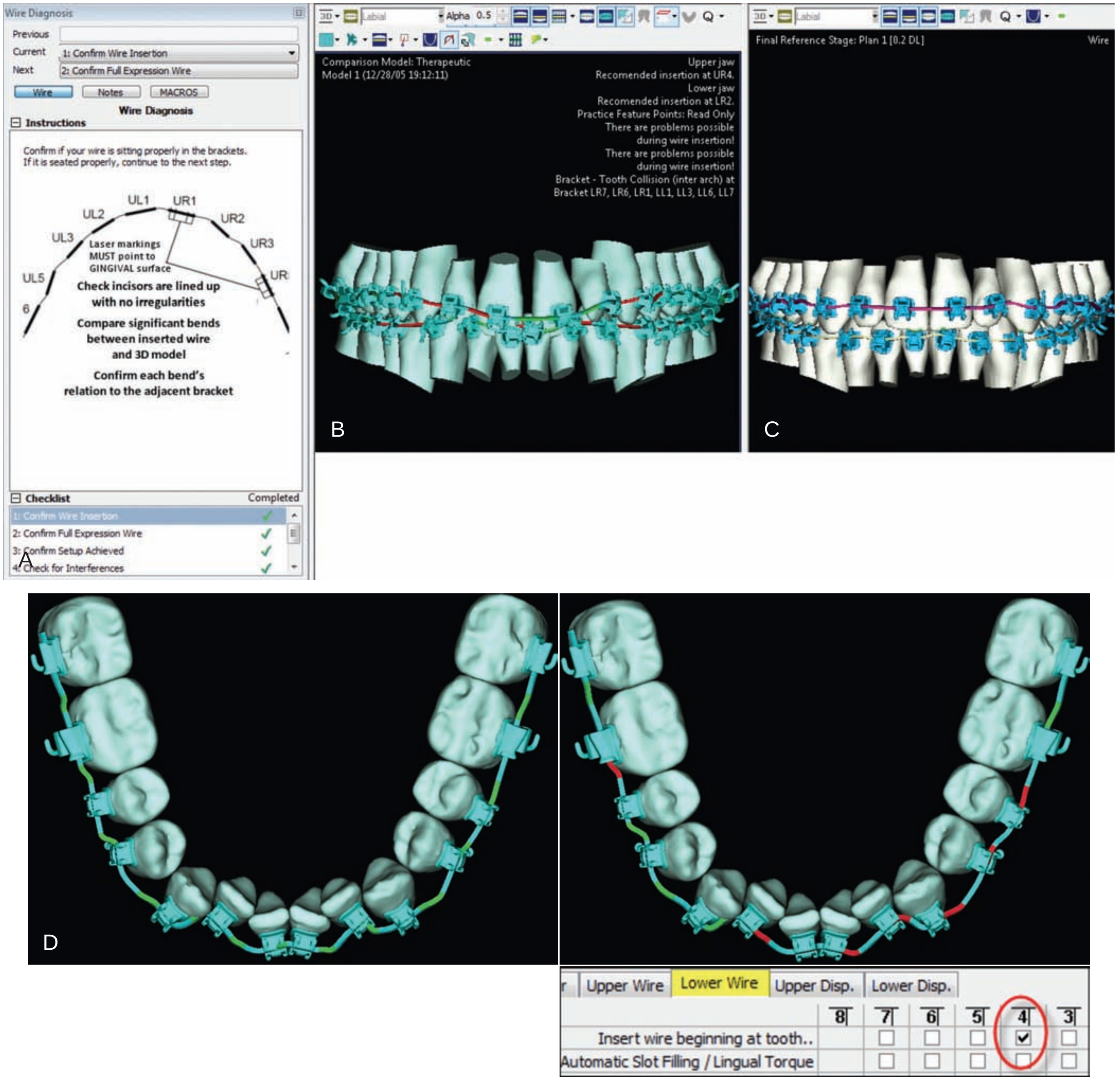
	8⌉	7⌉	6⌉	5⌉	4⌉	3⌉	2⌉	1⌉	⌈1	⌈2	⌈3	⌈4	⌈5	⌈6	⌈7	⌈8
Mesial (+) Distal (-) [mm]		-0.9	-1.0	-1.1	-1.0	-0.4	-0.1		0.3	-0.6	-0.6	-0.9	-0.9	-0.9	-0.6	
Buccal (+) Lingual (-) [mm]		-1.2	-0.1	-0.1	-0.7	-0.8	1.5	0.5	0.3	1.1	-1.0	-0.2	-0.5	-0.7	-1.3	
Occlusal (+) Gingival (-) [mm]		-0.3	0.4		0.2	-0.5	-1.1	0.5	0.3	-0.9	-0.6	0.3		0.3	-0.4	
Torque Facial (+) Lingual (-) [deg]		4		5	7	11	11	7	8	14	13	11		-5	3	
Angulation Mesial (+) Distal (-) [deg]		-9					-3	5		-3		-1		-3	-12	
Rotation Mesial (+) Distal (-) [deg]			-5	-1	20	18	20	-14	-28	13	-9	7	-4	-6	-4	
Mesial Gap (+) IPR (-) [mm]						-0.2	-0.2	-0.2	-0.2	-0.2	-0.2					

☑ Malocclusion Includes Max. / Mand. Alignment Adjustments

● Tooth Displacements

○ Bracket Displacements

FIGURE 20-12 **A,** Therapeutic model versus setup helps to plan tooth movement. **B,** Therapeutic model versus archwire helps read the archwire design.



Wire Diagnosis

Previous:

Current: 1: Confirm Wire Insertion

Next: 2: Confirm Full Expression Wire

Wire Diagnosis

Instructions

Confirm if your wire is sitting properly in the brackets.
If it is seated properly, continue to the next step.

Laser markings MUST point to GINGIVAL surface

Check incisors are lined up with no irregularities

Compare significant bends between inserted wire and 3D model

Confirm each bend's relation to the adjacent bracket

Checklist	Completed
1: Confirm Wire Insertion	✓
2: Confirm Full Expression Wire	✓
3: Confirm Setup Achieved	✓
4: Check for Interferences	✓

Comparison Model: Therapeutic
Model 1 (12/28/05 19:12:11)

Upper jaw
Recomended insertion at UR4.
Lower jaw
Recomended insertion at LR2.
Practice Feature Points: Read Only
There are problems possible during wire insertion!
There are problems possible during wire insertion!
Bracket - Tooth Collision (inter arch) at Bracket LR7, LR6, LR1, LL1, LL3, LL6, LL7

Final Reference Stage: Plan 1 [0.2 DL]

	8	7	6	5	4	3
Insert wire beginning at tooth..		☐	☐	☐	☑	☐
Automatic Slot Filling / Lingual Torque		☐	☐	☐	☐	☐

FIGURE 20-13 Archwire collision identification. **A,** Template generated for practice demonstrating optimal location for tying archwire. **B, C,** Archwire installation can be simulated on the therapeutic model to detect collisions. **D,** Archwire is in its final passive state.

The final bracket position on the target "setup" is used to evaluate if the archwire has worked out to completion (Figure 20-16). The value of this verification step cannot be underestimated, because in many busy practices treatment goals are generally forgotten and patient care continues with little progress achieved over time, a phenomenon I term "orthodontic flagellation." This is costly to both the patient and the practice. A visual reference definitively provides an effective "stopping rule" for care. Furthermore, patients commonly forget the goals of treatment. This may cause embarrassment to the doctor at the end of treatment when the patient questions the results. When a visual treatment plan is designed with the patient's participation in advance, the patient is aware of the end goal and is more accepting of the outcome. Furthermore, the plan is always visually accessible on the computer to show to a patient if the need arises. This is unlike the conventional practice where two different versions exist—one in the doctor's mind and the other in the patient's mind. A visual treatment

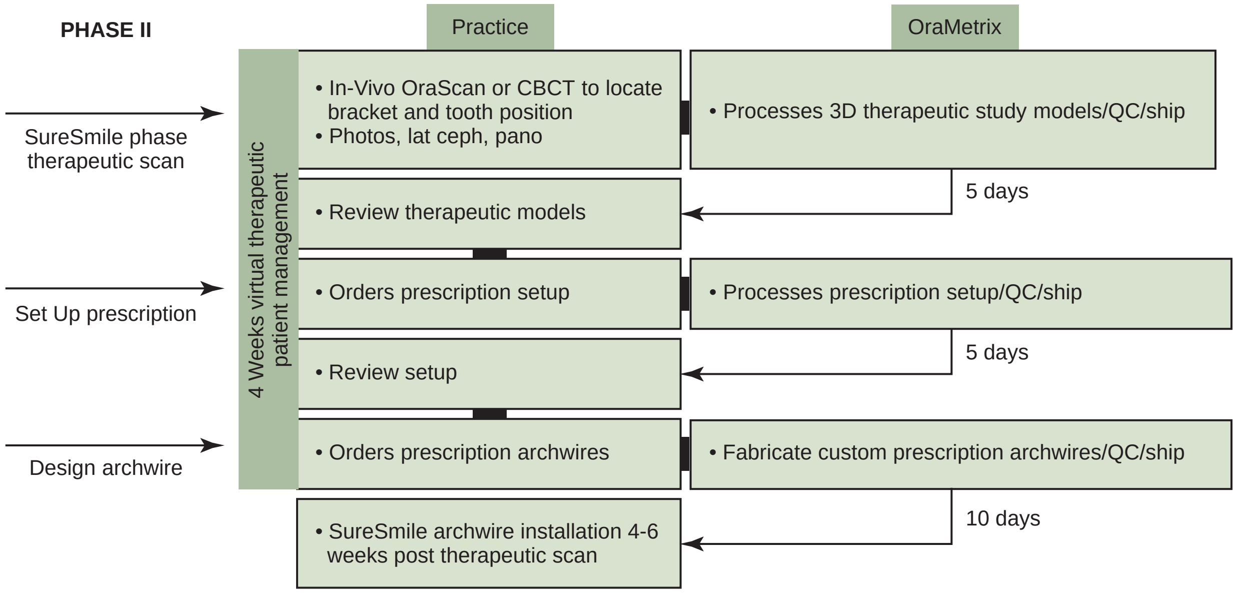

PHASE II
Practice
OraMetrix
SureSmile phase therapeutic scan
Set Up prescription
Design archwire
4 Weeks virtual therapeutic patient management
• In-Vivo OraScan or CBCT to locate bracket and tooth position
• Photos, lat ceph, pano
• Processes 3D therapeutic study models/QC/ship
5 days
• Review therapeutic models
• Orders prescription setup
• Processes prescription setup/QC/ship
5 days
• Review setup
• Orders prescription archwires
• Fabricate custom prescription archwires/QC/ship
10 days
• SureSmile archwire installation 4-6 weeks post therapeutic scan

FIGURE 20-14 Phase II SureSmile work tasks at the practice and laboratory with work delivery times.

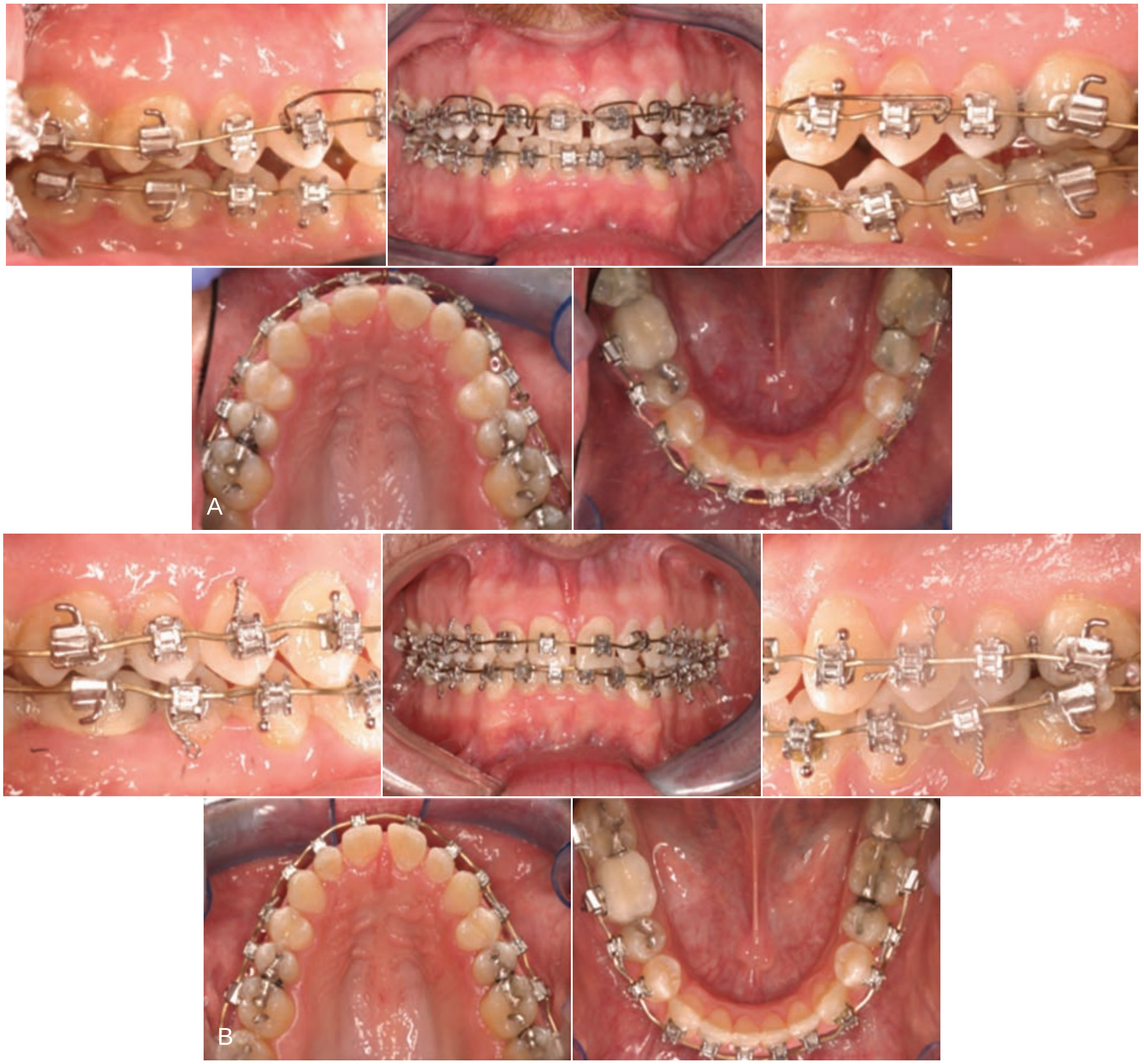


FIGURE 20-15 **A,** Insertion of 19- × 25-inch SureSmile archwire. **B,** Eight weeks postinsertion.

objective provides a set point for motivating patients and parents rather than the orthodontist stating, “We are trying to make them fit better.”

Outcome Evaluation Phase

This final model can be evaluated by 3-D inspection or by using the automatic grading system and by comparative analysis using the “best fit” registration method against the diagnostic, therapeutic, or target setup (Figures 20-17 and 20-18). Furthermore, to better analyze the patient’s response to treatment and the doctor’s ability to achieve his or her treatment objectives, the models can be selectively superimposed by “best fit” registration to the diagnostic, therapeutic, or “setup” models.

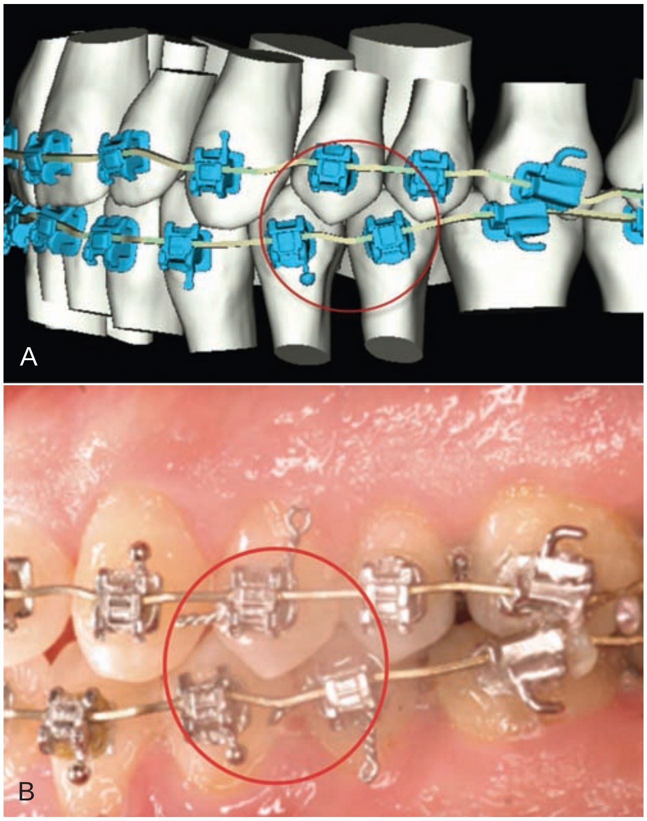


FIGURE 20-16 **A**, Final bracket position on target setup is matched against **B**, clinical situation to assess if archwire has worked out.

PROACTIVE DECISION MAKING

There are a number of approaches that may be used in planning care for a patient using the DDS model and/or the DTS model. For an accomplished clinician, these simulations do not take more than 10 minutes to accomplish. Using these tools effectively is a skill and can be learned only through deliberate practice. Practitioners new to digital tool sets should schedule extra time for simulation and other tasks as they build these skills. When the knowledge gained from these simulations is incorporated and sequenced appropriately in the management of a patient, not only do they add to efficiencies in care and better outcomes, they also increase patient safety by alerting the doctor to potential hazards.

Principle of Smart Orthodontics

The objective of simulations is to plan care with three objectives in mind: (1) it should be achievable, (2) it should require minimal tooth displacement, and (3) the plan should realistically reflect the ability of the therapeutic appliance under consideration. An example of using this approach in the correction of a functional shift accompanied with a posterior crossbite in the second molar area is shown (Figures 20-19 to 20-22).

Principle of Risk Analysis

I use this simulation to visualize whether my plan may result in the violation of anatomical constraints (Figure 20-23). Also, since the gingival tissue is designed to move in a 1 : 1 ratio with tooth movement, I am able to see the effect tooth movement has on gingival architecture and plan in advance for it (Figure 20-24). I can also inform the patient proactively about the potential risks associated with treatment.

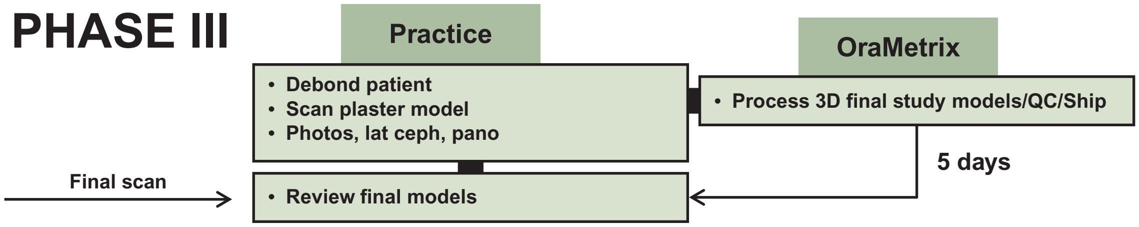
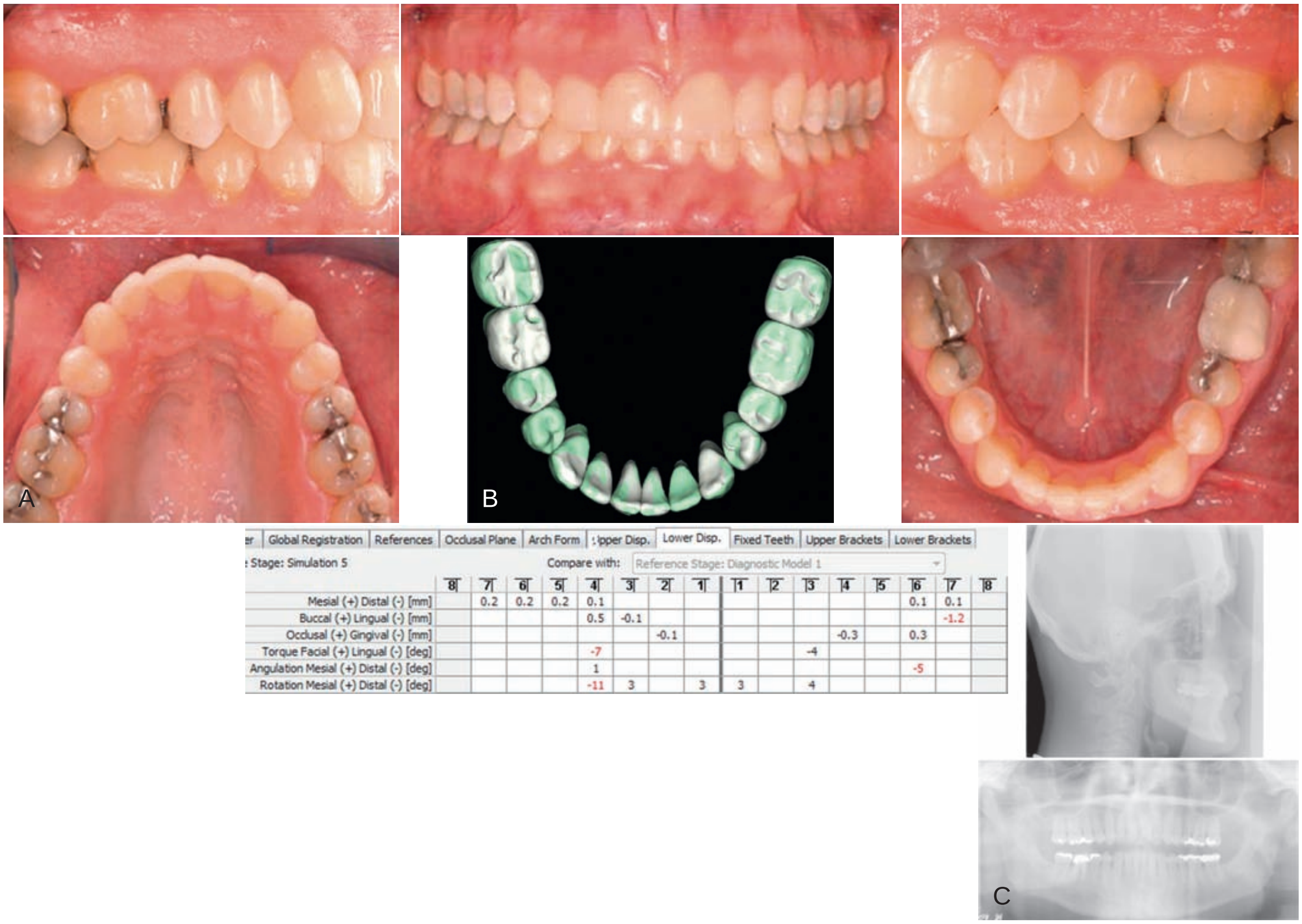


FIGURE 20-17 SureSmile process for the patient debond and final assessment.



: Stage: Simulation 5

Compare with: Reference Stage: Diagnostic Model 1

	8	7	6	5	4	3	2	1	1	2	3	4	5	6	7	8
Mesial (+) Distal (-) [mm]		0.2	0.2	0.2	0.1									0.1	0.1	
Buccal (+) Lingual (-) [mm]					0.5	-0.1									-1.2	
Occlusal (+) Gingival (-) [mm]							-0.1					-0.3		0.3		
Torque Facial (+) Lingual (-) [deg]					-7						-4					
Angulation Mesial (+) Distal (-) [deg]					1									-5		
Rotation Mesial (+) Distal (-) [deg]					-11	3		3	3		4					

FIGURE 20-18 **A,** Final photos with four anterior teeth restored with veneers. **B,** Superimposition of final models versus setup. **C,** Final x-rays.

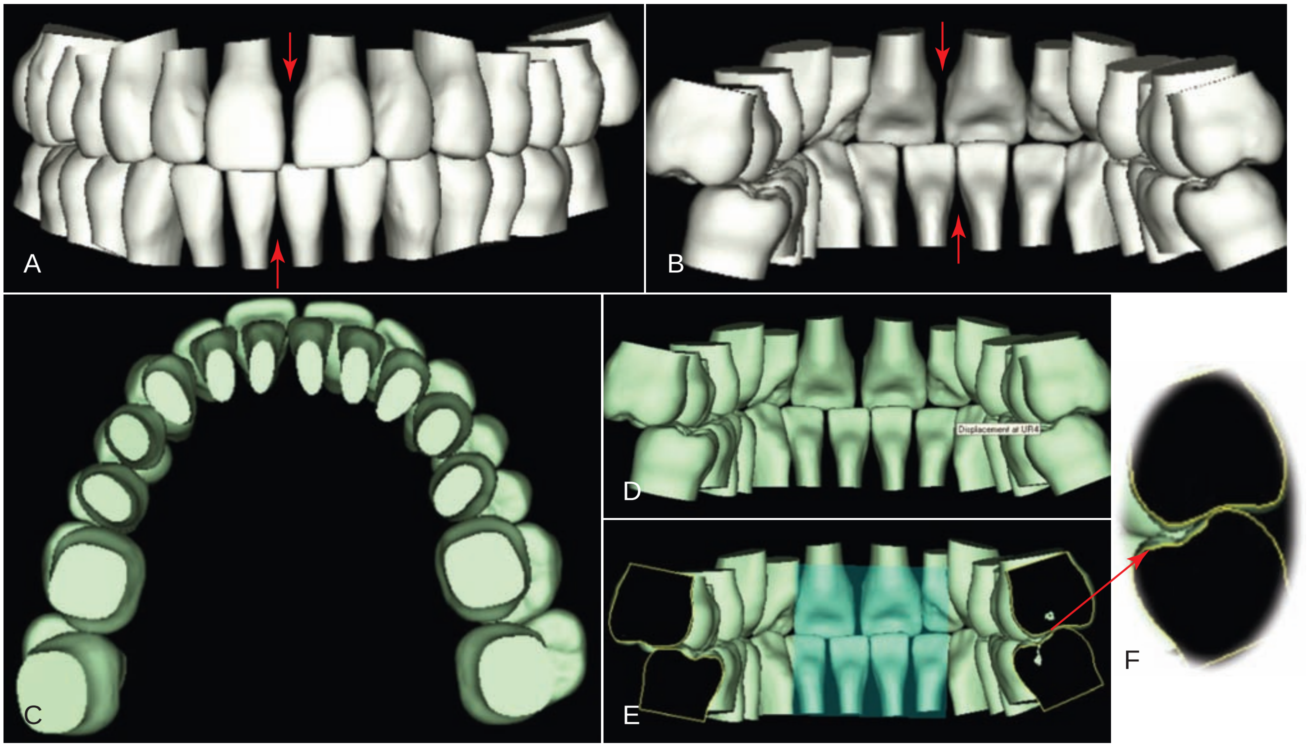
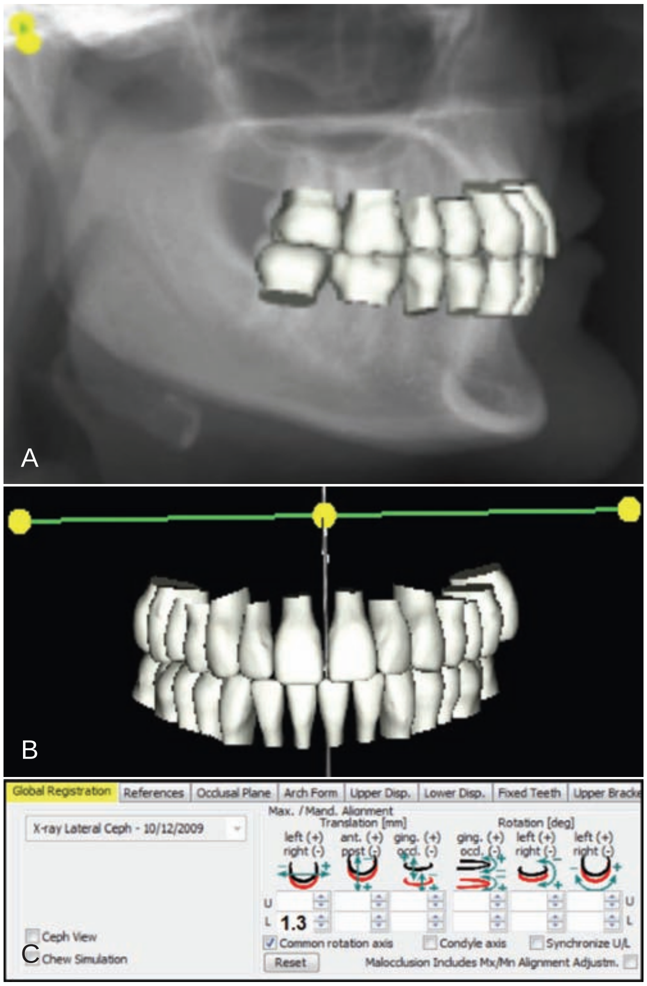


FIGURE 20-19 Smart tooth movement. **A–E,** Initial models showing functional shift and buccal crossbite in left second molar region. **F,** Note the contact in the upper right molar area.



X-ray Lateral Ceph - 10/12/2009

L 1.3

☐ Ceph View
☐ Chew Simulation
☑ Common rotation axis
☐ Condyle axis
☐ Synchronize U/L
Malocclusion Includes Mx/Mn Alignment Adjustm. ☐

FIGURE 20-20 Smart tooth movement. **A, B,** Center of rotation to simulate shift of mandible selected. **C,** Input for simulation of mandibular shift.

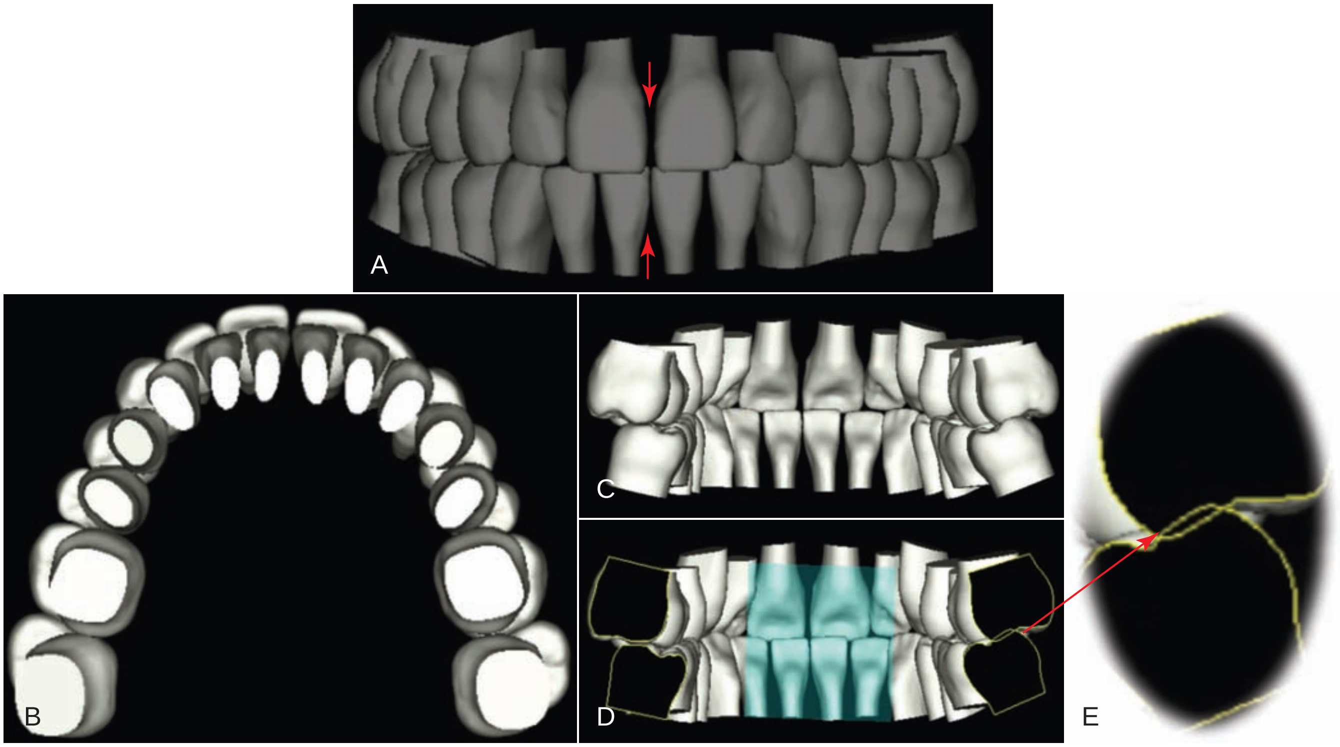
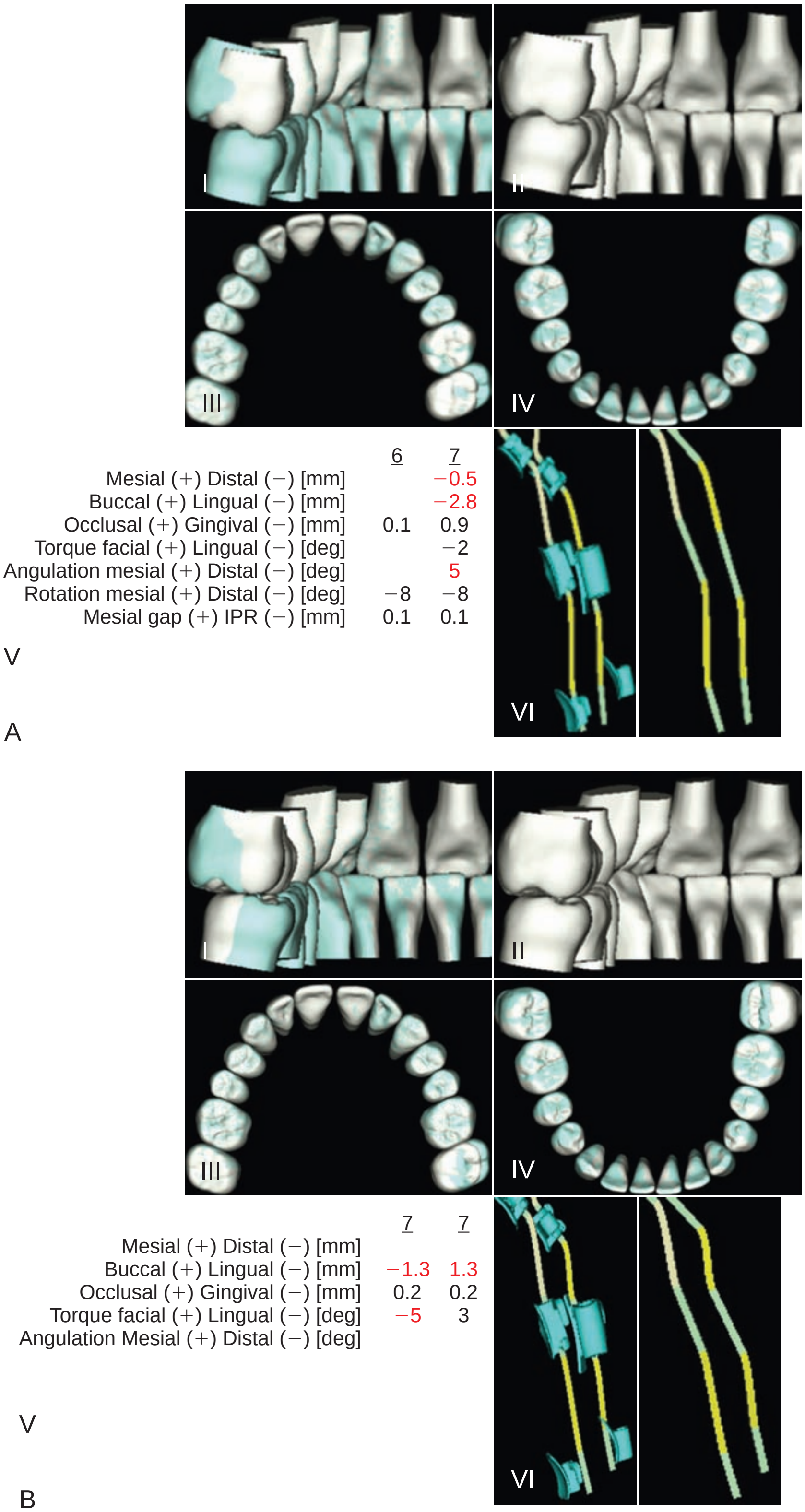


FIGURE 20-21 **A–D,** Mandible shifted to the patient's left. Note simulation of shift correction corrects midline but does not resolve the crossbite completely in the left molar region and crossbite also appears in the right molar region. **E,** Note interference that appears on the inclined planes as in the upper right molar area as mandibular shift is corrected.



	6	7
Mesial (+) Distal (−) [mm]		−0.5
Buccal (+) Lingual (−) [mm]		−2.8
Occlusal (+) Gingival (−) [mm]	0.1	0.9
Torque facial (+) Lingual (−) [deg]		−2
Angulation mesial (+) Distal (−) [deg]		5
Rotation mesial (+) Distal (−) [deg]	−8	−8
Mesial gap (+) IPR (−) [mm]	0.1	0.1

	7	7
Mesial (+) Distal (−) [mm]		
Buccal (+) Lingual (−) [mm]	−1.3	1.3
Occlusal (+) Gingival (−) [mm]	0.2	0.2
Torque facial (+) Lingual (−) [deg]	−5	3
Angulation Mesial (+) Distal (−) [deg]		

FIGURE 20-22 Smart tooth movement. Note residual crossbite is corrected by two different kinds of movements of the molars. **A, I–IV,** Upper left 7 is moved lingually. **V,** Tooth displacement values. **VI,** Targeted archwire design. **B, I–IV,** Residual crossbite corrected by movement of upper and lower 7's is consistent with the use of crossbite elastics. **V,** Note the displacement values of upper and lower 7's are reciprocal. **VI,** Targeted archwire design for reciprocal movement. This movement may be easier to accomplish and faster than the correction planned in **A.**

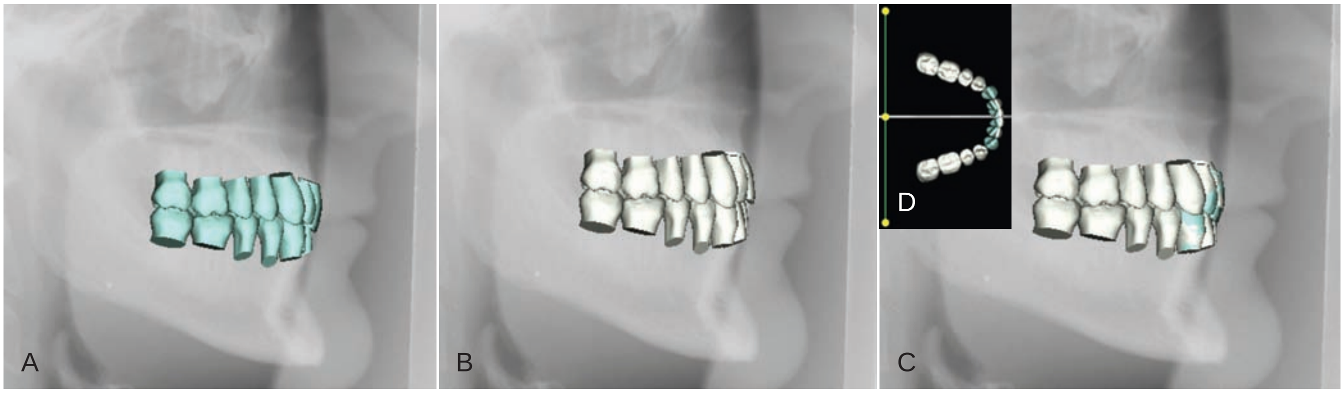


FIGURE 20-23 **A–D,** Cephalometric superimposition of the simulation and original model, registered on the lower second molars. Simulation model is in white and initial model is in blue.

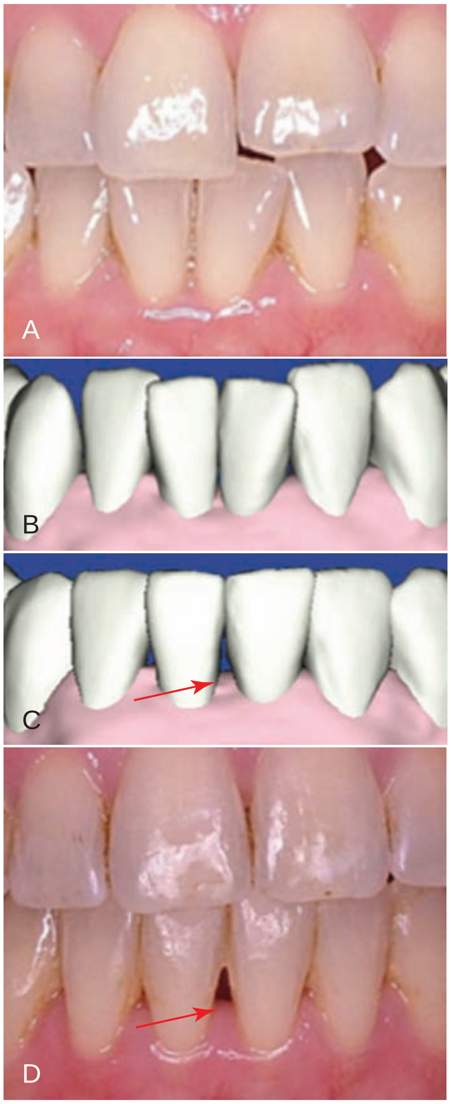


FIGURE 20-24 **A**, Virtual diagnostic model showing crowding of anterior teeth. **B,** Intraoral diagnostic photo showing crowding of anterior teeth. **C,** Virtual simulation model (IPR scenario) showing largest black triangle between the central incisors. **D**, In vivo condition at the end of treatment.

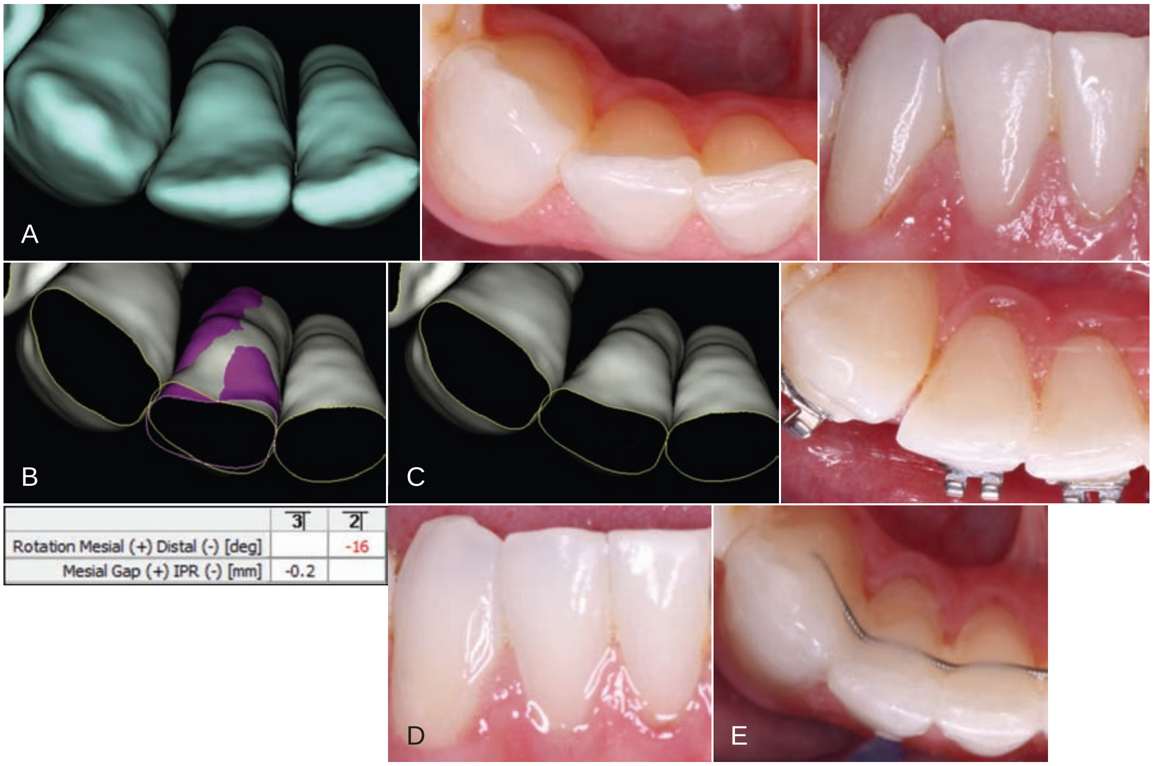
Principle of Constraint Recognition and Management

This simulation enables me to better understand where the teeth will collide during alignment and plan for strategic and proactive interproximal reduction (Figure 20-25). I can also see if bracket interferences will occur and how these interferences could affect tooth movement.

Principle of Anticipatory Orthodontics

The orthodontist can develop chronologic milestone-driven "best estimate" prediction simulations that may be shared with both patients and staff. Patients find them very useful in tracking their care progress. They become active collaborators in care, and their personal motivation to adhere to the treatment regiment increases substantially. The simulations also allow the staff to better understand treatment objectives, and the images provide them a template to assess orthodontic "vital signs" at each visit. The simulations also provide an excellent visual communication tool for both the doctor and staff to discuss the patient's progress in treatment at the chairside (Figure 20-26). This collaborative care is another hallmark of a patient-centered practice. After years of performing such predictive simulations and comparing them to the actual tooth movement, one can recognize patterns in tooth movement that may be incorporated in the simulations to achieve more realistic expectations.

Taking this one step further, we can envision a new approach to patient management that would be called "condition-based scheduling." In essence, the patient would monitor his or her progress against the anticipated movements, and when a milestone is reached, the patient would contact the practice for evaluation. This concept challenges the conventional approach of treating to the schedule rather than the patient's individual response. Philosophically, this is the "right" approach to



	3┐	2┐
Rotation Mesial (+) Distal (-) [deg]		-16
Mesial Gap (+) IPR (-) [mm]	-0.2	

FIGURE 20-25 Constraint detection and management. **A,** Mesial-out rotation of lower left lateral incisor is simulated. **B, C,** Note that when the tooth is rotated 16 degrees (and assuming no movement of the canine) then collision will occur on the distal surface of the lateral and the mesial surface of the canine. The overlap demonstrates the magnitude of the collision automatically. I use this as a guide to show how much IPR is performed. **D, E**, Final photographs.

care. The patient's response to treatment should dictate when he or she needs to be seen.

PRINCIPLES OF TARGETED THERAPEUTICS

Achieving effective treatment outcomes in an efficient manner requires a proactive therapeutic strategy driven by diagnosis in all therapeutic phases of treatment. One needs to recognize that a full expression archwire based on the targeted setup is only one of the many therapeutic solutions that can be designed with digital analytic and treatment planning techniques and fabricated with the robot to achieve predictable and controlled tooth movement. The versatility of designing diagnostic-driven and condition-based appliances for managing a dynamic biological system is where the true strength of robotic-assisted orthodontics resides. The following describes the concept of the adaptive prescription, which provides the foundation of the design principles in managing patient care with robot-assisted orthodontics.

Adaptive Prescription

The straight archwire concept of treatment is designed on the principle of a deterministic system. The operating paradigm is that a bracket with an ideal prescription placed ideally on a tooth will lead to an ideal response. This strategy at best is naive and needs to be challenged. A bracket cannot be placed ideally most of the time. Anatomic constraints due to severely rotated teeth, partially erupted teeth, and variation in tooth morphology are just some clinical examples that limit their ideal placement.

Furthermore, just a slight alteration in bracket position, such as to avoid interferences, can substantially affect the expression of a bracket prescription, forcing the doctor to practice reactive orthodontics. The altered expression of the bracket as a result of repositioning can be corrected for only by archwire bending (Figure 20-27).

Even with fully erupted teeth and the use of indirect bonding techniques, ideal bracket placement remains an enigma because of the lack of reliability in seating the transfer trays.[8,9]

Indirect bonding also does not overcome the impact of inconsistencies in tooth morphology; it simply provides for an efficient way to improve precision and place brackets en masse at the chairside. Another problem with the straight arch appliance brackets resides with the bracket prescription. Straight wire prescriptions are standard and do not reflect the patient's needs. Furthermore,

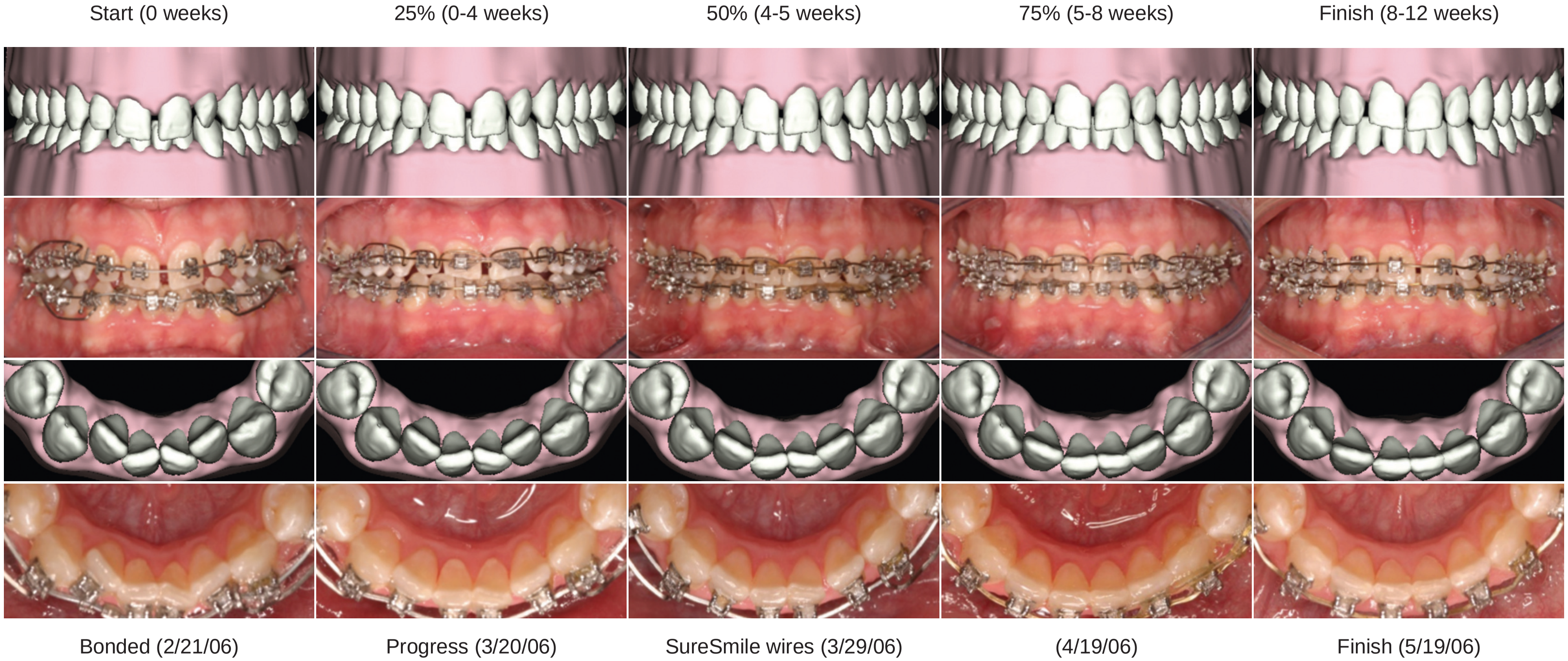


FIGURE 20-26 Anticipatory orthodontics. Progress milestones have been established with simulations.

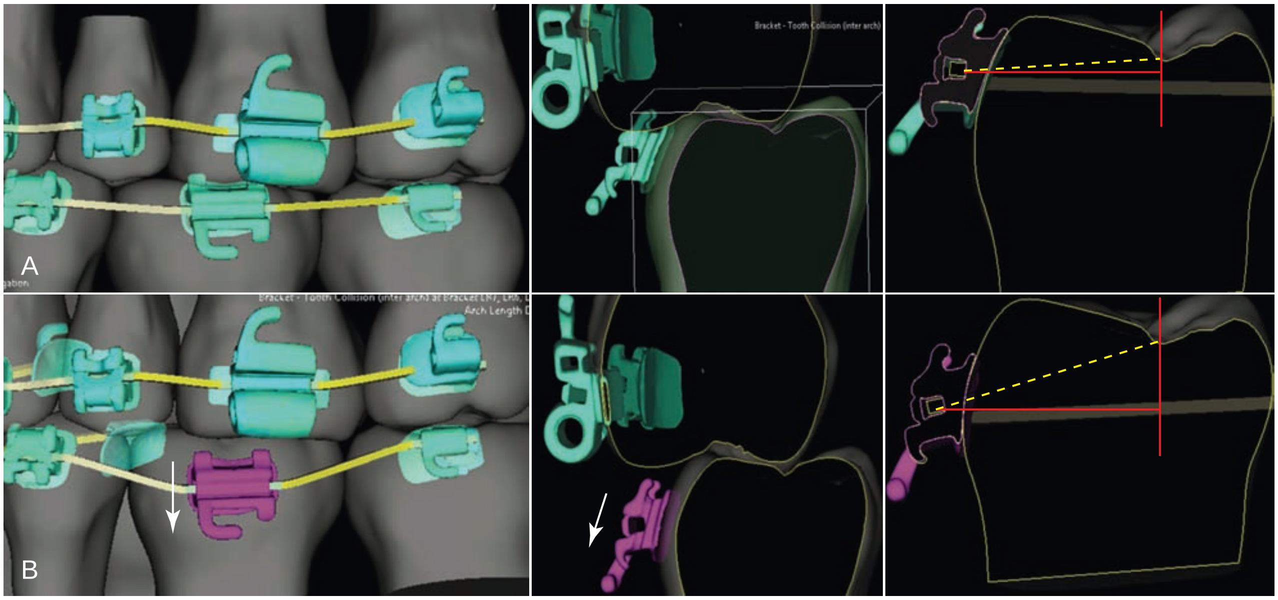


FIGURE 20-27 Reactive orthodontics driven by bracket position. This example demonstrates the effect of vertical bracket repositioning on torque. **A,** Clipping plane view shows that the occlusal wings of the lower 6 are colliding with the upper 6. Note the torque of the bracket. **B,** The bracket is repositioned gingivally to avoid collision. Note the effect this has on torque expression. Many times adjustments are made in bracket placement without compensating for these effects, which then leads to reactive therapeutics with the archwire bending to manage the resulting spurious tooth movement.

the bracket slot dimensions demonstrate poor manufacturing tolerances and diminish control.[10,11] One might argue that customized brackets may solve this issue, but this is not necessarily true.[12,13] The slots in customized brackets are milled just as for the off-the-shelf brackets and therefore are subject to the same issues of poor manufacturing tolerances. Again, the conflict between vertical bracket placement and tooth morphology cannot be reconciled by customized brackets. Any change in torque values manifests itself not only in relative vertical discrepancies but also in buccolingual dimensions, setting up a vicious cycle.

Most important, however, is that orthodontic care occurs in an environment that reflects a complex adaptive system. John Holland has defined the complex adaptive system as, "A dynamic network of many agents acting in parallel, constantly acting/reacting to other agents." The overall behavior of the system is a result of huge number of decisions every moment with multiple variables affecting treatment response (Figure 20-28). A "deterministic system" does not involve randomness in the future state of the system.

There are many clinical instances such as poor patient compliance, unplanned anchorage loss, and spurious tooth movement that force the doctor to reassess his or her treatment objectives in mid-treatment. In such situations, deterministic designed appliance systems fail to account for the altered therapeutic requirements to manage to the new care objectives. They do not provide the clinician the flexibility to override the prescription built into the appliance short of rebooting or resorting to craft-based reactive therapy. Robotic-assisted archwire bending driven by therapeutic diagnosis provides the doctor unprecedented control to modify the targeted prescription at will and to adaptively manage the dynamic clinical situation. It remains almost impossible to build constriction or expansion or selectively stage the expression in a static prescription offered by a bracket without resorting to archwire shaping or bending.

Conventional straight archwire therapy and indirect bonding with or without customized prescriptive brackets are limited in their capacity to provide control in the management of orthodontic patients. An adaptive prescription built into the archwire with robotic-assisted orthodontics provides a more realistic approach to manage orthodontic care, which is a manifestation of a complex adaptive system.

Principle of Image-Guided Smart Bracket Placement and Archform Selection

By using 3D modeling simulation tools, I try to understand the impact of tooth morphology on bracket–archwire interaction. I also use the tool to determine where I should place the brackets to achieve my treatment goals, minimize collisions, and avoid the risk of bracket failure. Additionally, I use the simulations to develop a visual guide to help me position the brackets better at the chairside (Figures 20-29 and 20-30). Also, with the simulation tools I will plan for the selection or modification of the straight archwire form that I will use initially in the pre—SureSmile phase of treatment.

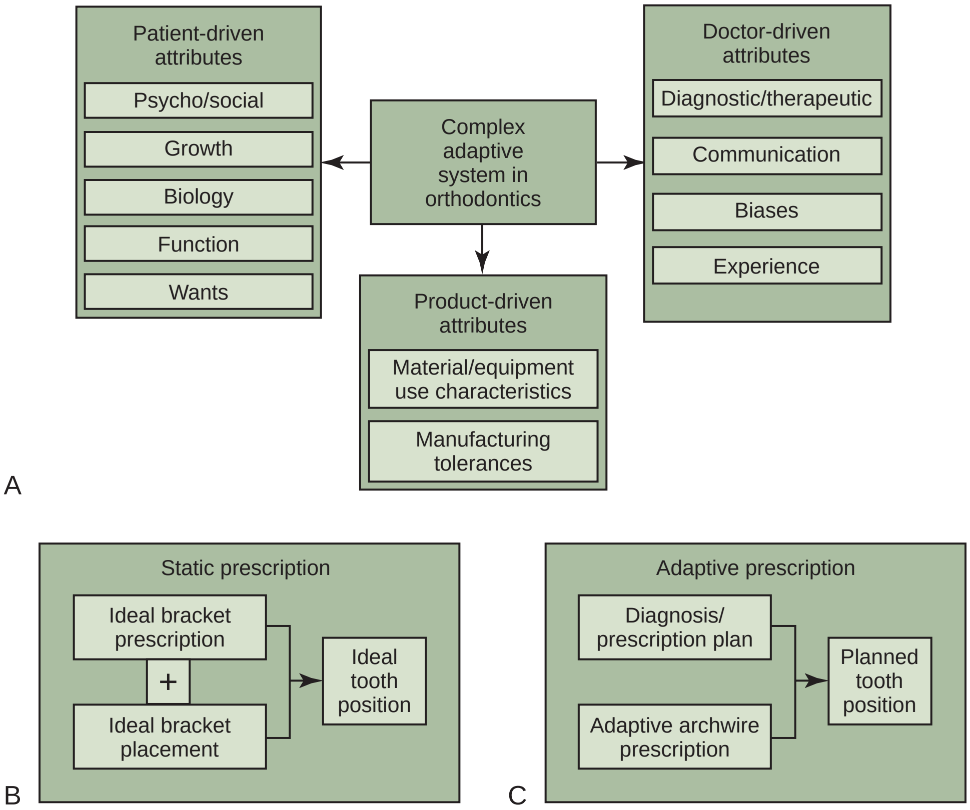


FIGURE 20-28 **A,** Factors affecting treatment response. **B,** Assumptions in appliance-driven mechanotherapy. **C,** Adaptive prescription therapy best serves in management of the complex adaptive system such as in orthodontic care.

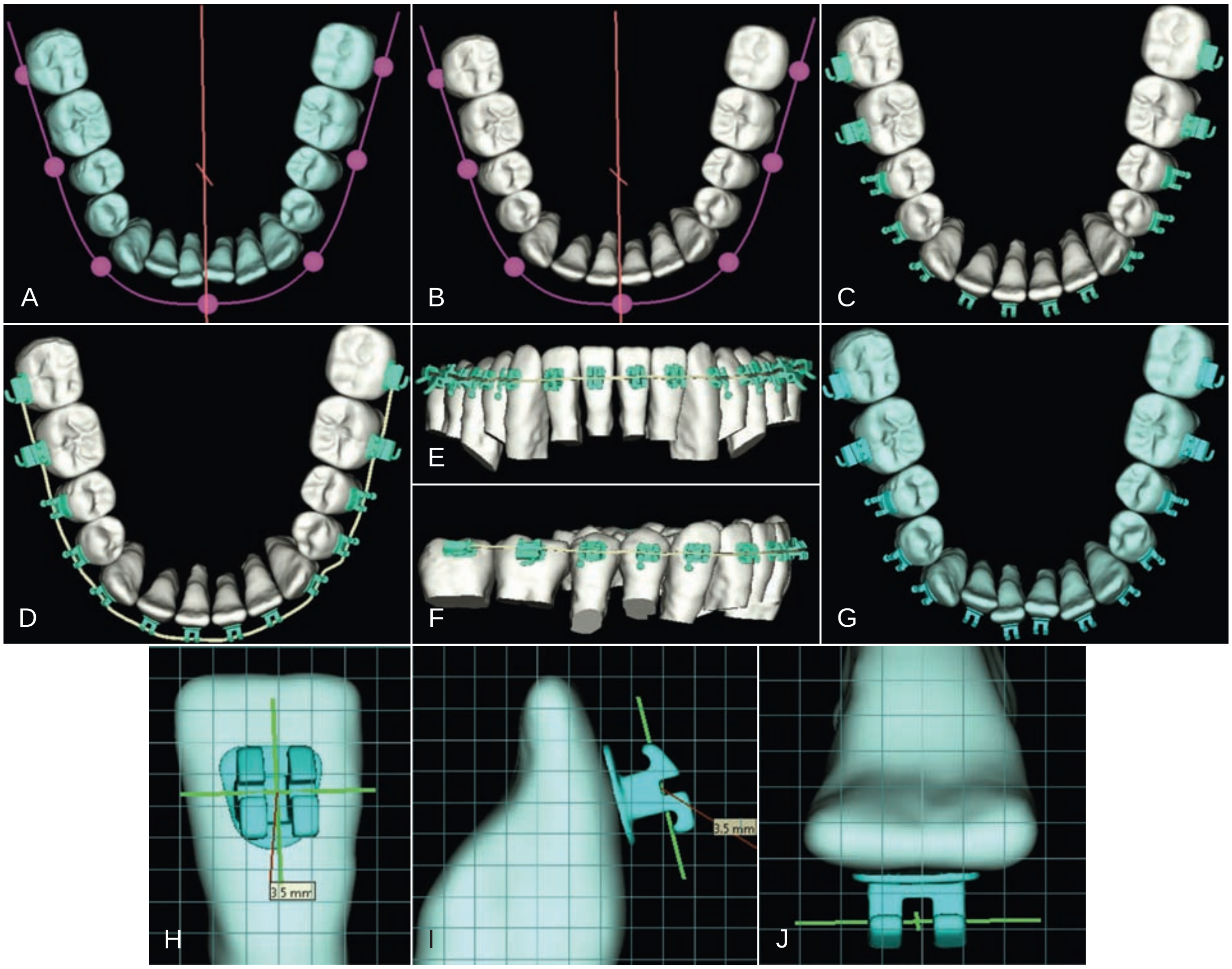


FIGURE 20-29 Smart bracket placement. **A,** Initial model with selected treatment archform. **B,** Simulation of tooth alignment and leveling. **C,** Automatic bracket placement to achieve desired result. **D–F,** Note that despite optimization of bracket placement, archwire bends will be required to achieve desired result. **G–J,** Coordinate transfer used to place brackets on original model; also note that the bracket position on each tooth can be visualized and measured to guide placement.

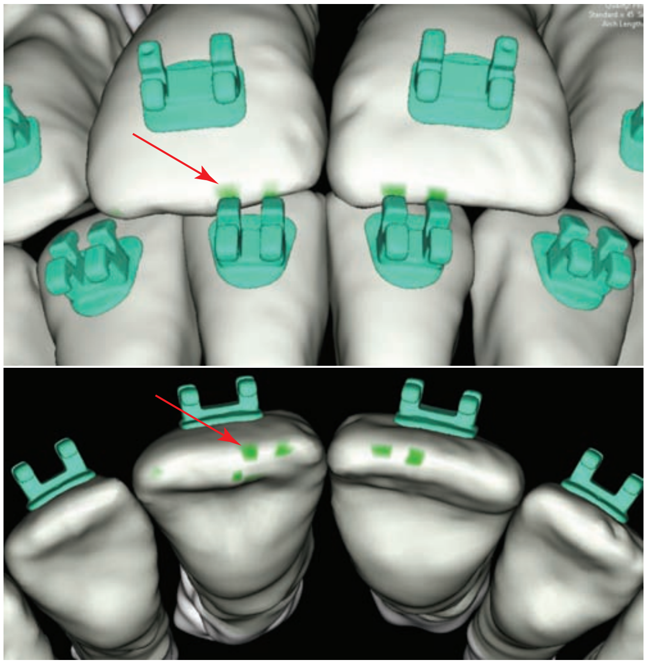


FIGURE 20-30 Bracket collision can be detected in advance of placement and avoided.

Principle of Minimal Archwire Replacement

In the pre–SureSmile therapeutic phase, I commonly use superelastic nitinol archwires, and my goal is to minimize archwire changes through the appropriate selection of material, archwire cross section, and transformation temperature (Figure 20-31). If tooth geometry leads to inconsistent force systems, I may resort to segmental mechanics to achieve the desired control. The principle of concurrent mechanics that I discuss later also minimizes replacement therapy.

Principle of Constraint Management

As mentioned earlier, if warranted by treatment objectives, IPR may be performed at the initial appointment to minimize any potential collisions between the teeth. This allows for quicker alignment and leveling. Interferences between opposing teeth can prevent their movement through collision. Bond bite blocks early in treatment to disclude the arches and prevent collisions from occurring (Figure 20-32).

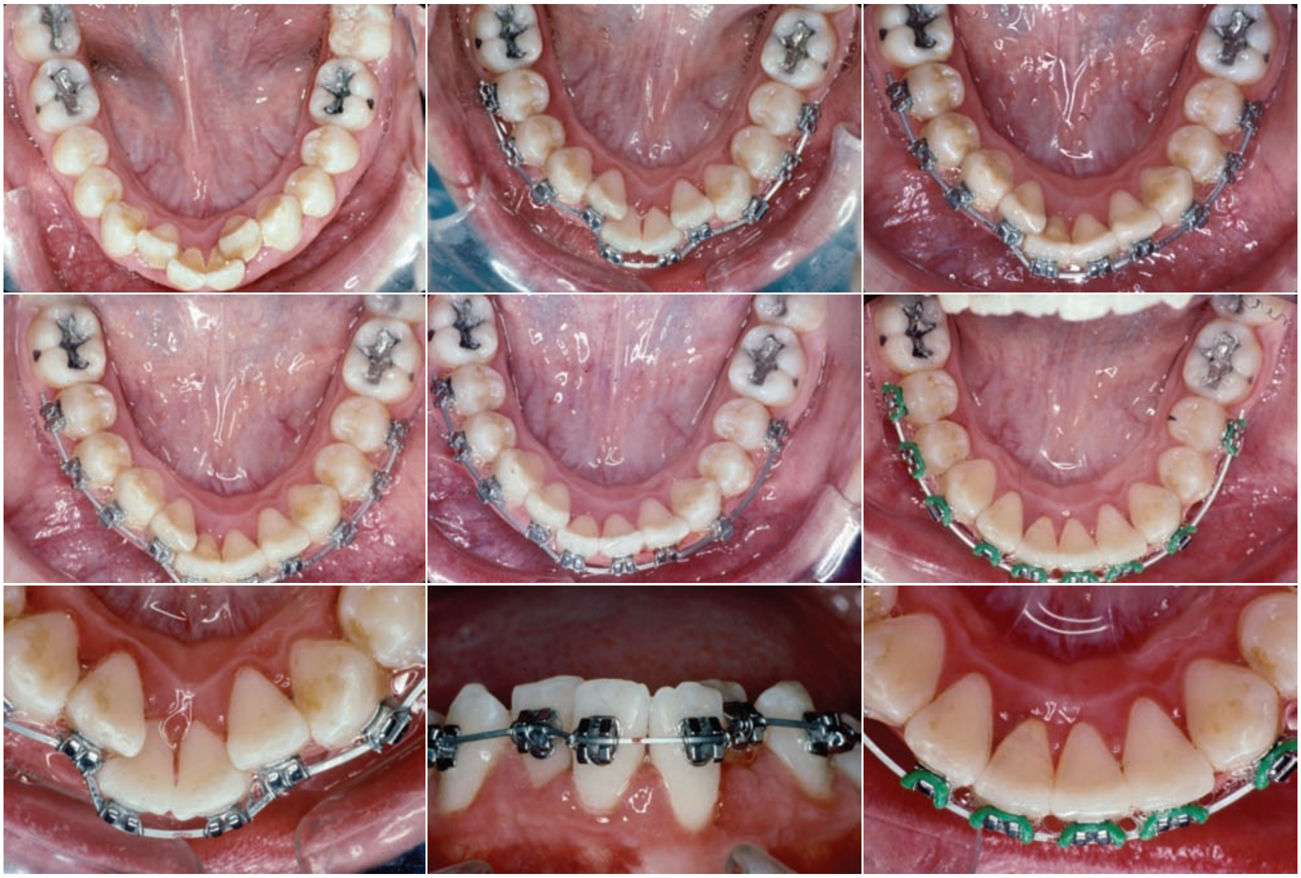


FIGURE 20-31 Minimal replacement alignment achieved in 4 months with initial 0.19- × 025-inch CuNiTi A_F 40°C archwire that was fully engaged.

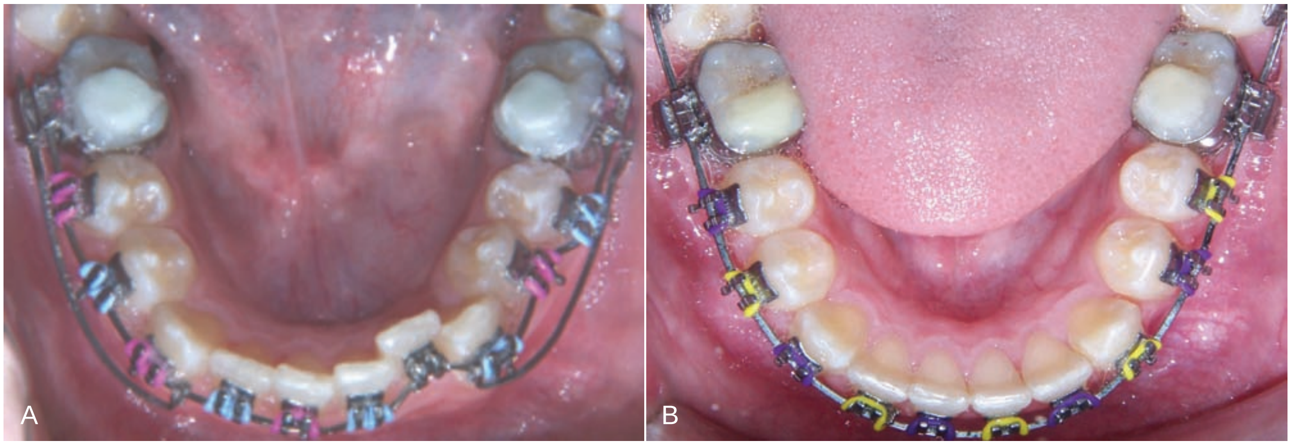


FIGURE 20-32 **A, B,** Posterior bite blocks bonded to prevent interarch collisions.

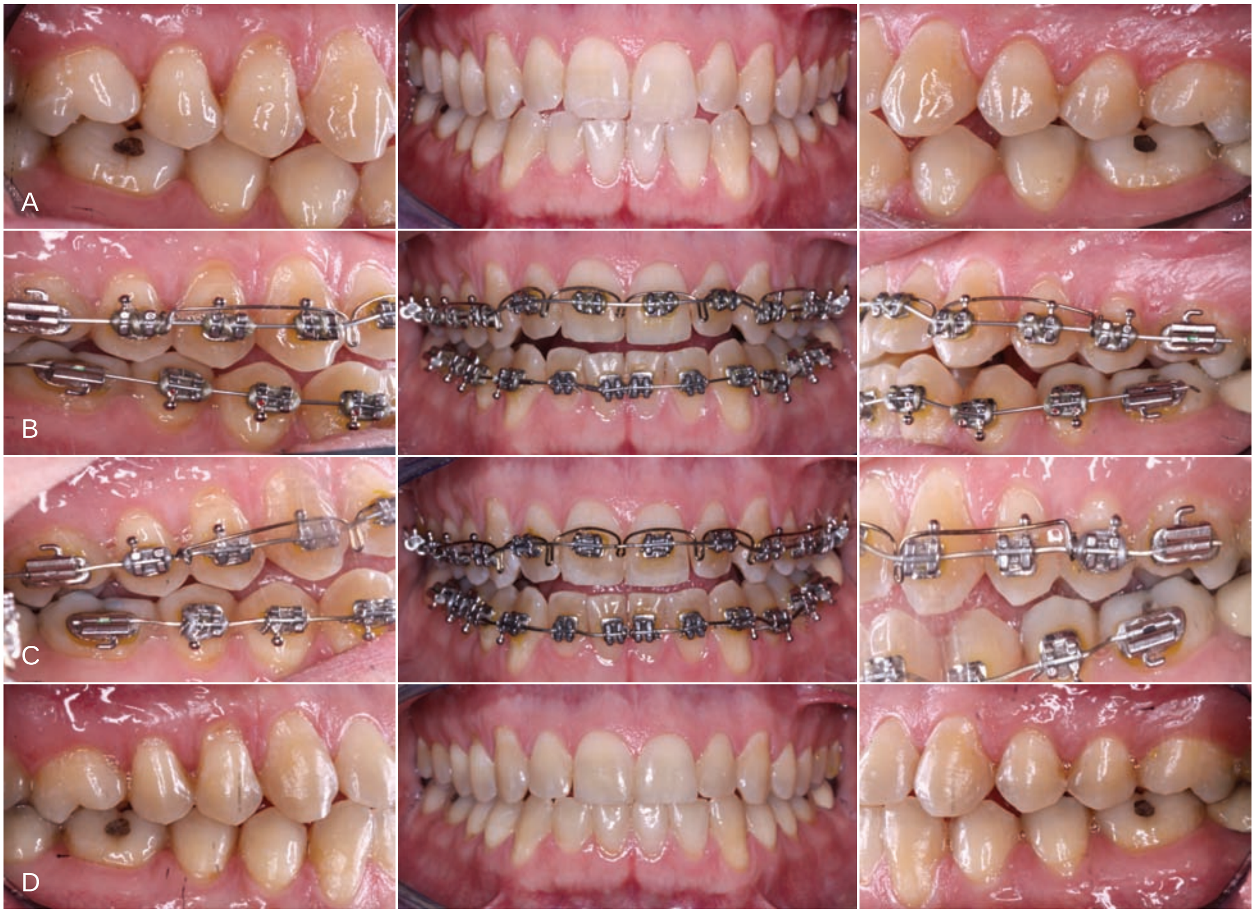


FIGURE 20-33 **A–D,** Concurrent Mechanics ART™ (Atlanta Orthodontics). Torquing springs are being used at the onset of treatment with 17″ × 25″ CuNiTi 35°C archwire to correct edge to edge bite. The bite is opened anteriorly with posterior bite blocks to minimize anterior interference during correction.

Principle of Concurrent Mechanics

When required, auxiliary appliances such as torquing springs, tip-back springs, and elastics may be used from the start of treatment. One may generate complementary force systems to gain better control of tooth movement and to achieve multiple treatment goals, such as alignment leveling and space closure in parallel (Figures 20-33 and 20-34).

Principle of Additive/Subtractive Bending, Preferential Staging, and Shaping

The expression of the digitally designed and robotically constructed archwire can be very effectively influenced to provide unprecedented control of tooth movement by either adding or subtracting bends at any point in the archwire or as a whole to achieve different levels of archwire expression.

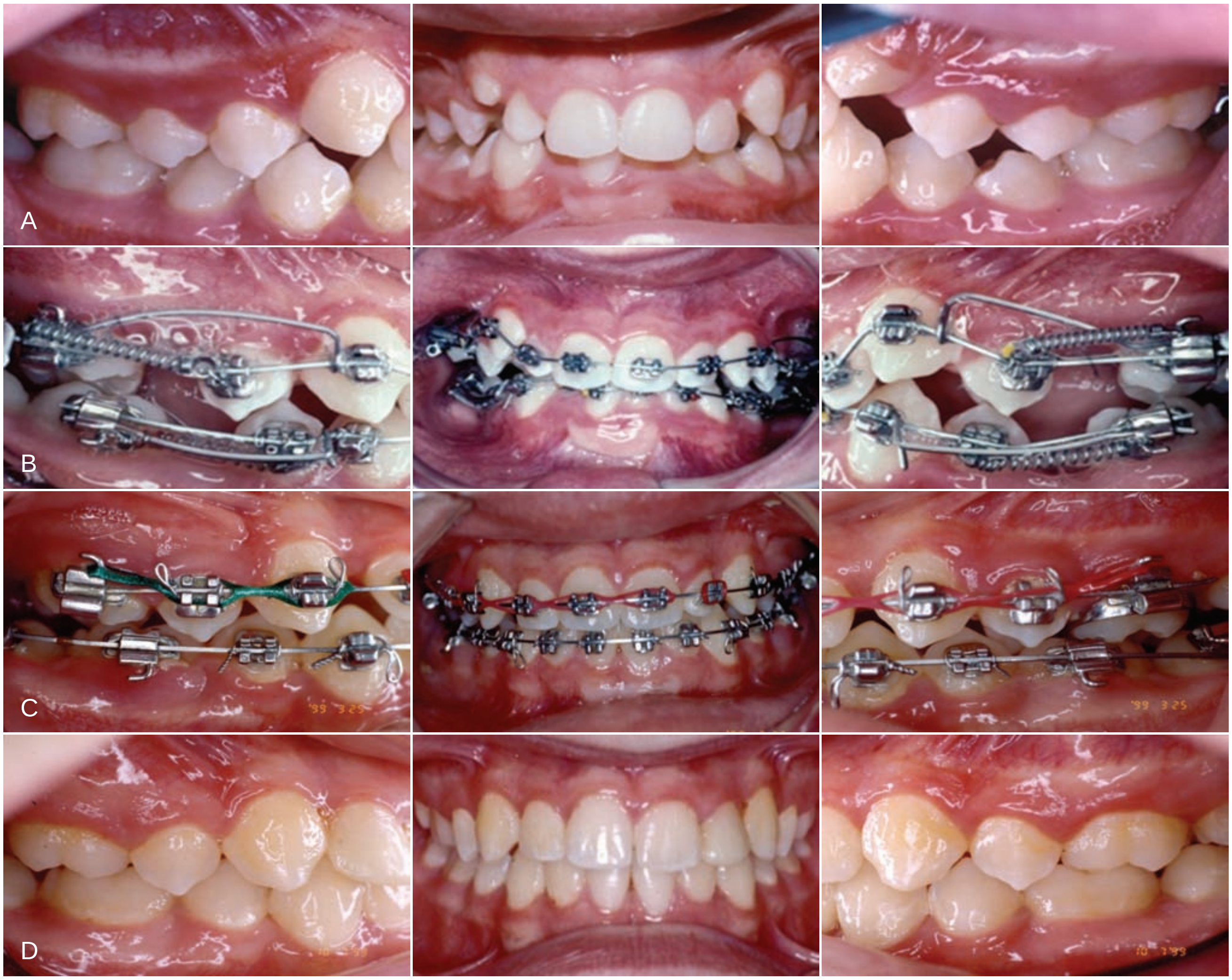


FIGURE 20-34 **A–D,** Concurrent mechanics. Sliding mechanics are being used to close space. The initial wire is a 0.17- × 025-inch CuNiTi A_F 35°C. Tip-back springs fabricated from 0.17- × 025-inch TMA were used to aid in leveling and minimize the tip forward of the buccal segments and distal crown tipping of the canines during space closure.

A full-expression, 100% active archwire can be designed for use from the start of treatment (see Figure 20-9). The expression may also be staged incrementally to control the amount of tooth displacement, especially in situations where the patient has a low threshold to pain, is not compliant, or is on an extended vacation (Figure 20-35).

An added dimension of control can be achieved by limiting bends to any one plane of space. For example, control can be achieved by removing all bends except for the first order, or creating a straight segment to achieve sliding mechanics during space closure (Figure 20-36).

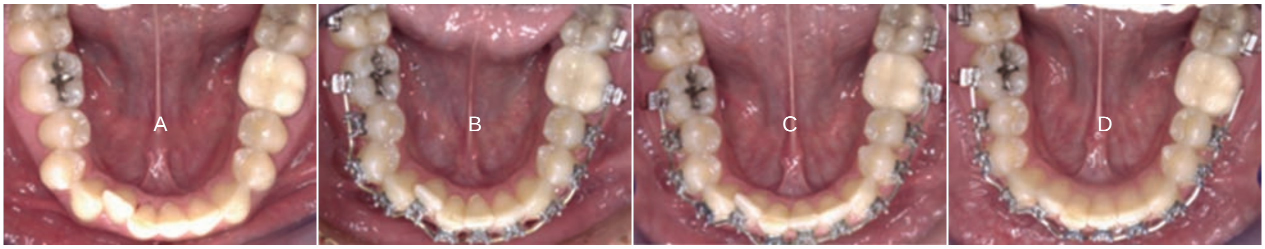
A curve of Spee, reverse curve, expansion, and constriction can all be designed into the archwire to build additive forces or subtract the reactive forces when using elastics.

Principles of Consistent Force Systems and Reactive Force Management

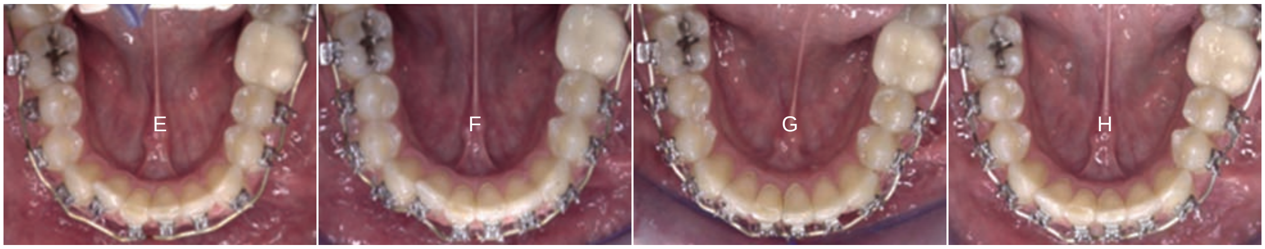
There are many situations where the unmanaged use of straight archwires will create inconsistent force systems leading to spurious tooth movement (Figure 20-37). This can be prevented by designing passive and reactive elements. Furthermore, hybrid archwires can be designed with both active and passive elements to better distribute the reactive forces and target the active forces (Figure 20-38). Passive archwires can be designed to minimize side effects of Class 2 mechanics (Figure 20-39).

Principle of Complementary Force System

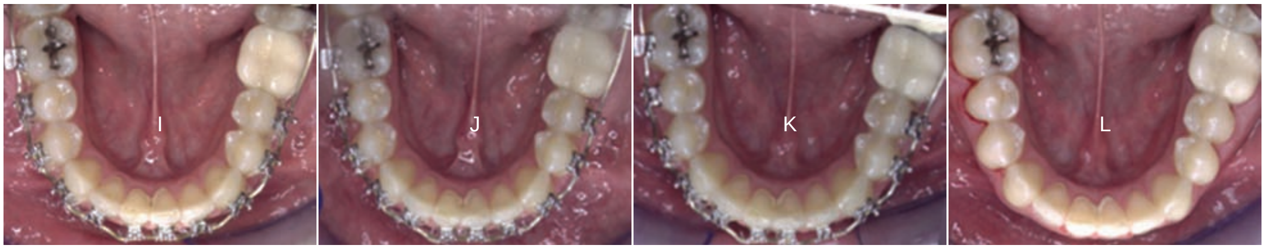
Many times toward the end of treatment, mild to moderate Class II or Class III correction remains unachievable



Initial 4/4/02 | Wires 5/9/02 (50% wire) | Progress 8/29/02 (50% wire) | Progress 10/3/02 (50% wire)



(Pre) 100% wire 10/5/02 | (Post) 100% wire 12/5/02 | Progress 1/3/03 (100% wire) | Progress 3/6/03 (100% wire)



Progress 5/15/03 (100% wire) | Progress 6/5/03 (100% wire) | Progress 6/26/03 (100% wire) | Final 6/26/03

FIGURE 20-35 Progressive SureSmile expression archwire. **A,** Initial. **B,** SureSmile archwire with 50% expression inserted. **C,D,** Progress with 50% SureSmile expression archwire. **E,** SureSmile archwire with 100% expression inserted. **F–K,** Progress with SureSmile 100% expression archwire. **L,** Finish.

despite long-term elastic wears. The most common reason for this is that bracket archwire coupling may impose reactive force constraints and fight the Class II or Class III elastic forces. This may be designed for in-bracket placement but becomes a daunting task, as this requires precision placement in all three planes of space. This kind of complex bracket placement is difficult to accomplish clinically. Instead, when using a digital tool set, such situations can be anticipated on the target "setup" and the virtually designed archwire can be made to complement the force system generated by the Class II or Class III elastics (Figure 20-40).

Principle of Optimization of Archwire and Material Selection

It is crucial to understand that the availability of different archwire materials and sizes and shapes of archwires increases the doctor's need to be judicious when selecting archwires and to guide his or her decisions based on material characteristics, the patient's condition, the desired treatment objectives, and whether elastics are being used. High load–deflection rate materials such as Elgiloy offer greater control of reactive segments, while superelastic archwires provide long-acting sustained forces that are beneficial for active movements over a long span.

The capability of being able to bend nitinol wire and retain its superelastic characteristics with robotic-assisted archwire bending offers the orthodontist a number of distinct advantages: (1) the ability to establish torque control very early in treatment extends its use and minimizes the number of replacements needed, (2) "biological friendly" forces can be applied through the entire range of care, and (3) torque control does not require the use of a near full-size archwire. It can be accomplished by accommodating for slop in the region of interest. Such a situation can occur when substantial anterior crowding demands the use of a smaller–cross-section archwire anteriorly, while posteriorly a single tooth such as the second molar requires torque.

EFFICACY AND EFFECTIVENESS

A number of studies have been designed to understand the efficiency and effectiveness of using robotic-assisted

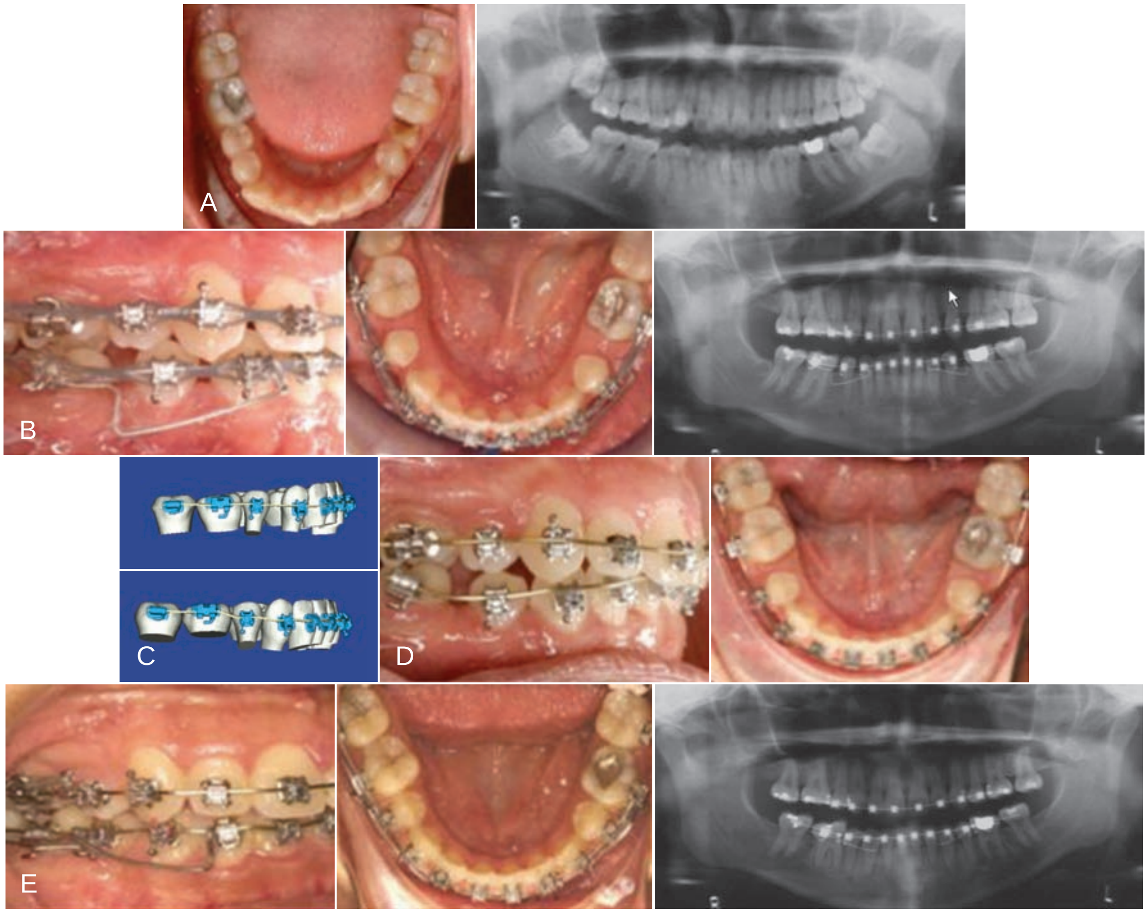


FIGURE 20-36 SureSmile archwire designed to enable sliding mechanics. **A,** Initial photograph and panorex. **B,** Initial half of the space has been closed on straight archwire. **C,** Two types of SureSmile archwires are designed, one for space closure. It is straight distal to the canines and has full expression anteriorly. The second archwire will be used after space is closed. It is the final archwire. **D,** Progress with SureSmile wires. **E,** Space is closed on the SureSmile wire.

orthodontics. Saxe and colleagues[14] studied 62 patients treated with advanced digital technology with a similar control sample and showed that the mean total months for treatment using the SureSmile process was 14.7 months versus 20 months for conventional methods ($p < .001$). The ABO OGS grades were 14% lower (better) than conventional treatment. A recent study by Alford et al.[15] also showed that treatment time with SureSmile was reduced by about 30% compared with conventional treatment and also that the CRE scores were 11% better.

To this point, we have analyzed over 12,000 patient records to understand the effectiveness of SureSmile. The results clearly demonstrate that technology-driven diagnosis and treatment favorably impact treatment time across the spectrum of practices and types of malocclusions. The median treatment time for SureSmile patients with Class I is 15 months (conventional = 24 months); Class II, 13 months (conventional = 23 months); and Class III, 16 months (conventional = 25 months).[16] Recent research by Patel et al.[17] at the University of Oklahoma has demonstrated no statistical differences in root resorption between robotic-assisted technology and conventional. Future studies need to be conducted to further understand both the efficiency and effectiveness of this technology in the management of orthodontic patient care. (To view several comprehensive patient histories, please go to www.orthodontics-principles-techniques.com.)

SUMMARY

Our profession is at the threshold of reinventing itself. We have the ability to transform our orthodontic care environment in which quality thrives by using enabling technology and applying the science of “process management” to evolve from a “craft-based” to a “patient-centered professional-based” care model.

We have the unique opportunity to adapt and customize care to specific patient needs, streamline our clinical protocols by embracing evidence-based care and evidence-farming, establish new benchmarks in care, and embrace system-minded thinking.

Some may perceive these advances as a step toward loss of personal autonomy and craft. Some may also fear that the new integrated digital tools and processes

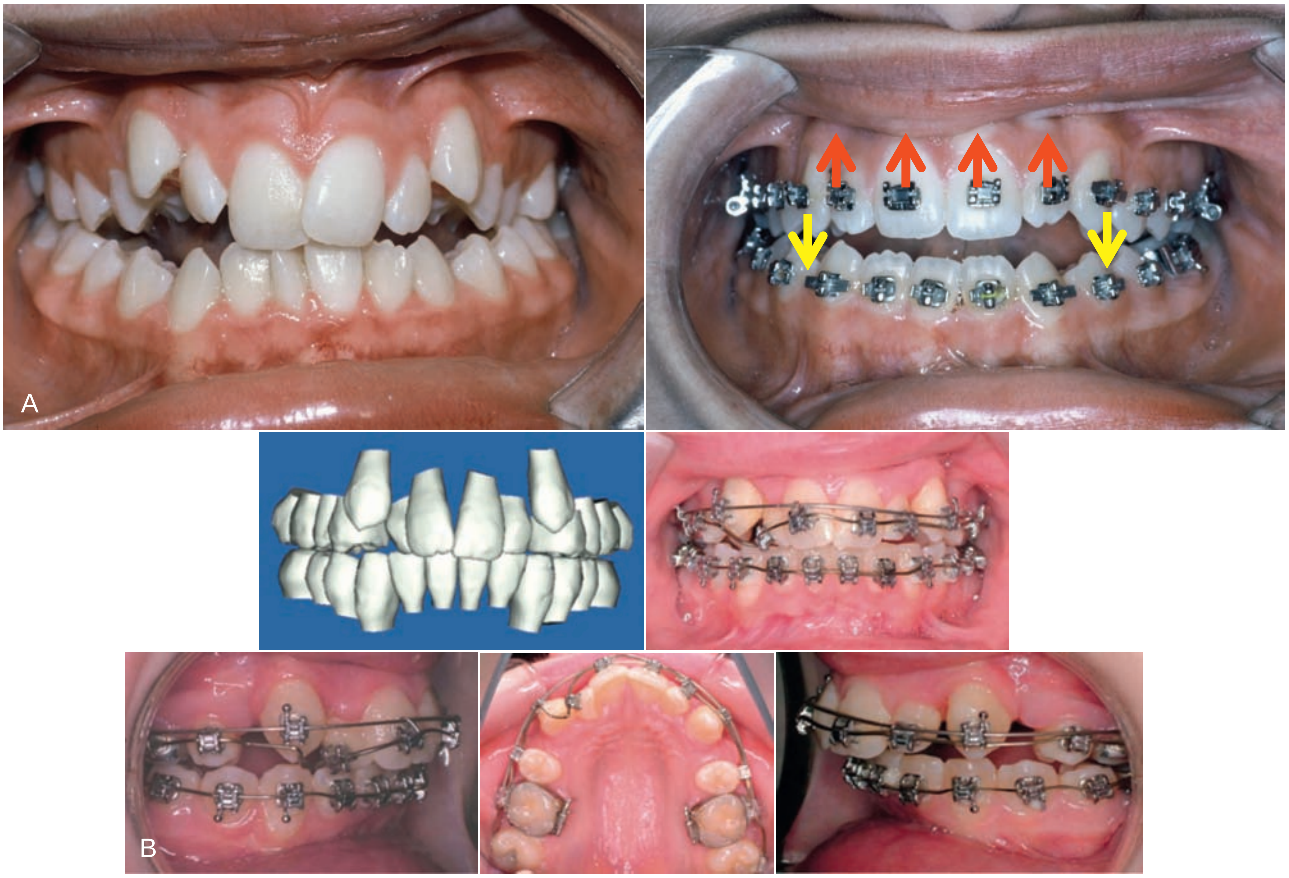


FIGURE 20-37 Passive SureSmile bypass wire to control inconsistent force systems. **A,** A common side effect of extruding canines with a continuous archwire is the intrusion of the anteriors, which creates an anterior openbite. **B,** The therapeutic strategy to minimize this side effect is to design a passive bypass archwire and piggyback an active archwire to extrude the cuspids. The bypass archwire helps stabilize the reactive segment and minimize side effects.

cause distance between the doctors and their patients, causing a loss of the "human connection" that most of us prize. Both of these fears are misplaced. Technology and processes, when viewed as enabling, provide unprecedented control for the doctor and staff to deliver better care.

We must view each practice as a "practice of one" and hold ourselves accountable to giving the best in care for each of our patients. We must subscribe to the practice of providing, the right treatment for the right patient at the right time and avoid at every cost the lure of "market-driven" orthodontics.

The word *metanoia* is an interesting word that entered our language from the Greek during the late Renaissance. Merriam-Webster online defines it as *"a transformative change of heart; especially: a spiritual conversion."* The question is, are we ready to experience a *metanoia* regarding how we practice orthodontics? Are we ready for the mind shift technology now allows us, the cultural shift to embrace the patient centered, professional-based model? After all, as Don Berwick states, "Every system is perfectly designed to achieve the results it gets."

Acknowledgments

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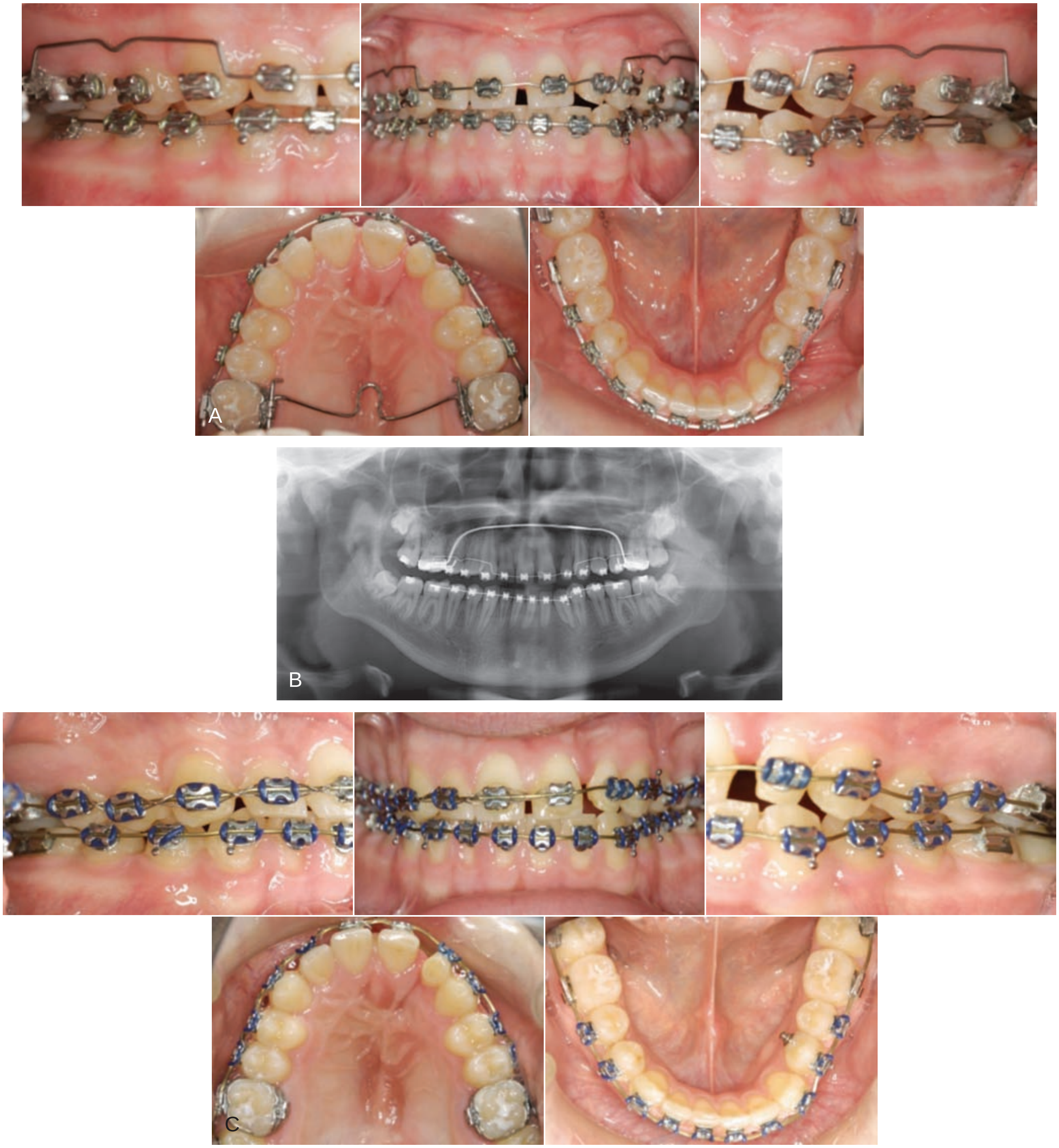

FIGURE 20-38 **A–F,** Hybrid SureSmile archwire design. A combination of passive and partially progressive bends is used to expand the lower left buccal segment. A continuous archwire would have had the tendency to expand both sides by creating a passive archwire from the lower left canine to the second molar on the right. A relative rigid reactive segment is established that distributes the reactive forces better. In addition, by designing progressive expansion active bends 50% followed by 100% on the left buccal segment, displacement of the teeth is better titrated, minimizing the potential of spurious movement.

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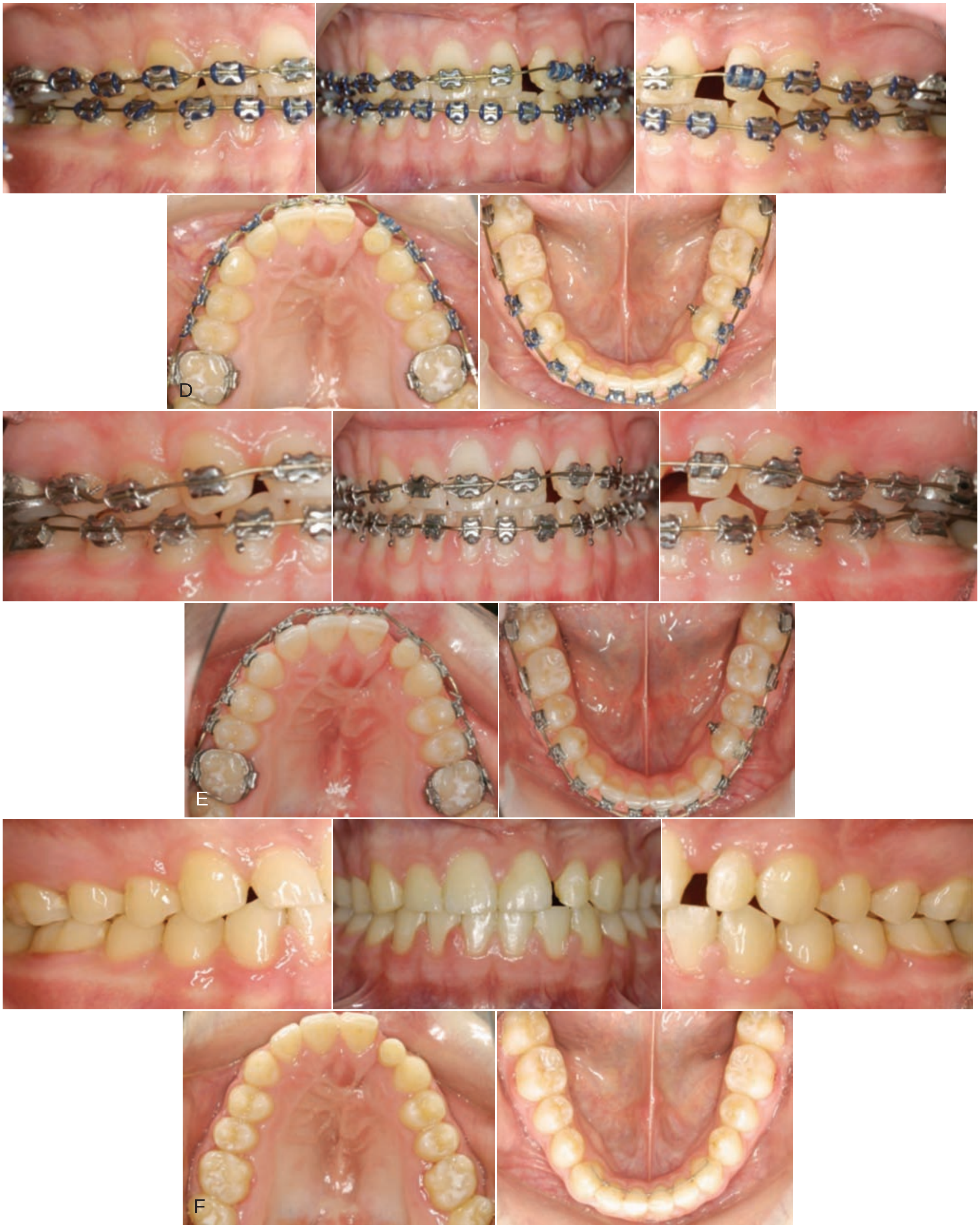

FIGURE 20-38, cont'd

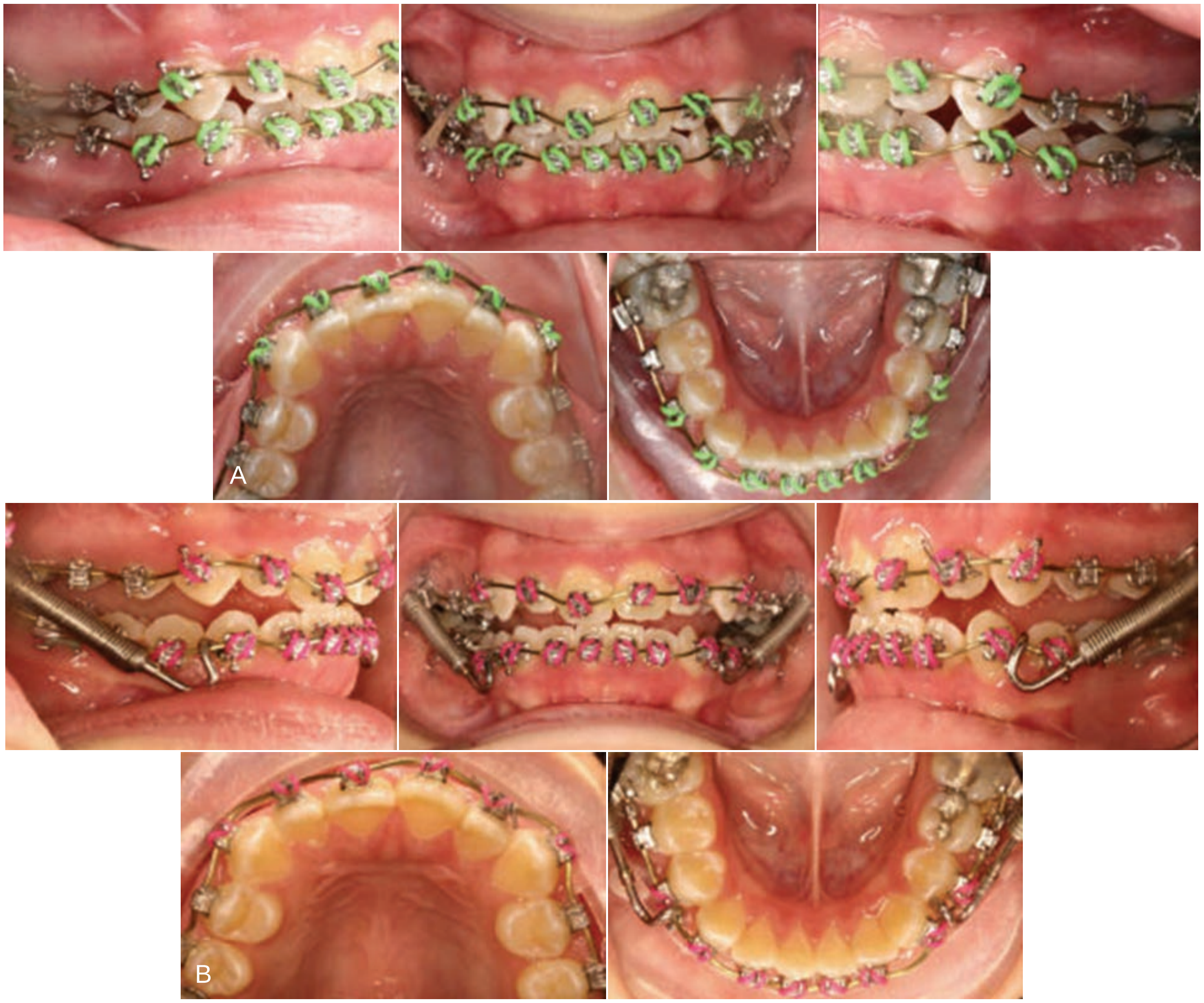

FIGURE 20-39 **A, B,** Class II correction with Forsus (3M Unitek) spring/passive 19- × 25-inch CuNiTi A_F 35°C SureSmile archwires are used for anchorage in the upper and lower dentition.

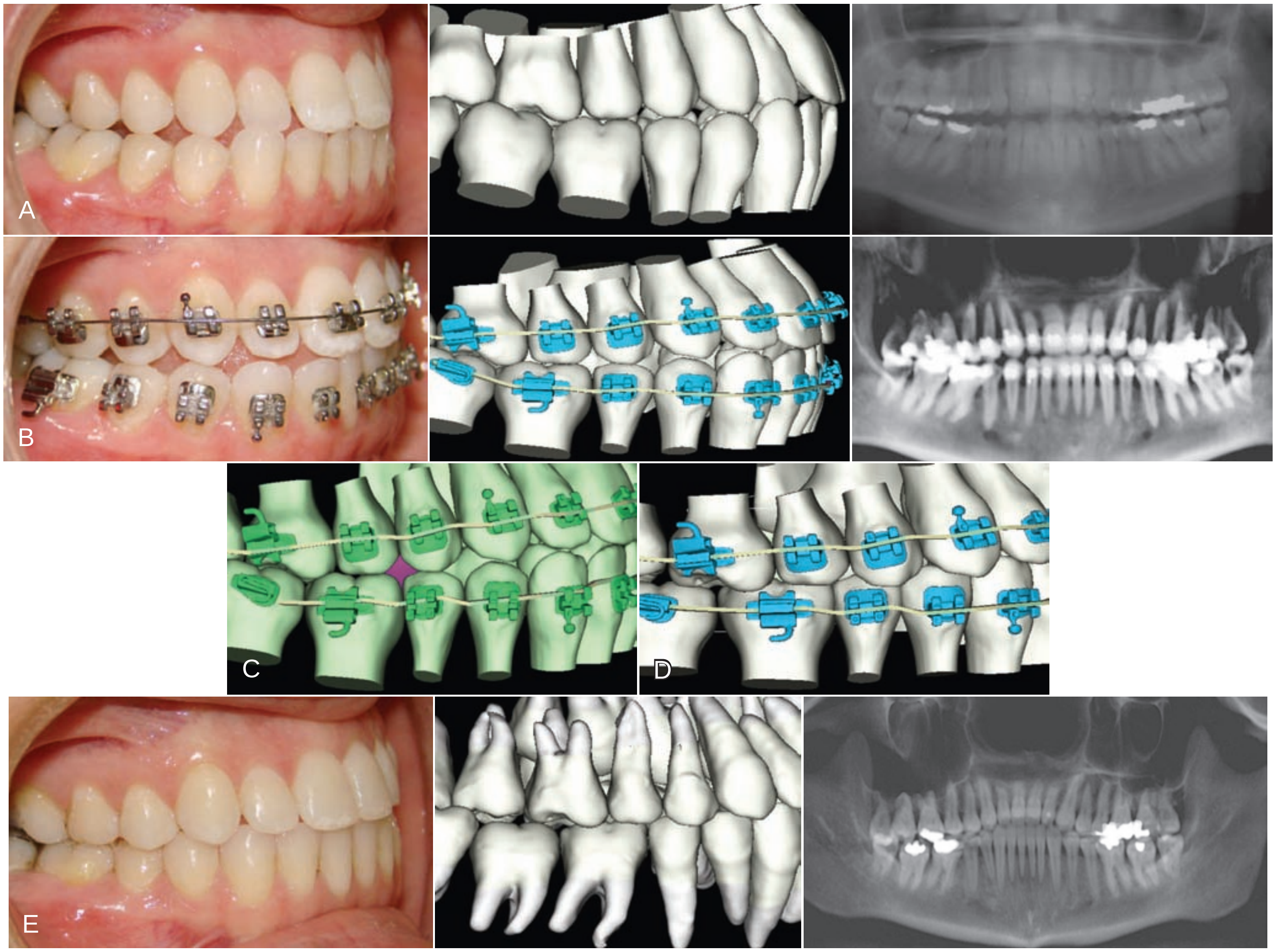

FIGURE 20-40 Complementary force system. **A,** Note patient has a Class III occlusion on the right buccal segment. **B,** Prior to SureSmile therapeutic phase, the Class III correction remains unresolved although the patient has been cooperative and has been wearing Class III elastics for 6 months. **C, D,** In the target setup, the dentition in the buccal segment is subtly set to correct the Class III in the lower bicuspid canine area. Note the archwire bracket geometry reflecting this. **E,** Patient continued elastic wear with the SureSmile archwire. Correction in occlusion is achieved as planned in the setup by building dentoalveolar compensations.

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CHAPTER

21

Bonding in Orthodontics

Björn U. Zachrisson, Tamer Büyükyilmaz

OUTLINE

- **Bracket Bonding**
  - Bonding Procedure
    - *Cleaning*
    - *Enamel Conditioning*
    - *Sealant, Primers*
    - *Bonding*
  - Types of Adhesives
    - *No-Mix Adhesives*
    - *Light-Polymerized Adhesives*
    - *Light Sources*
    - *Glass Ionomer Cements*
  - Brackets
    - *Plastic Brackets*
    - *Ceramic Brackets*
    - *Metal Brackets*
    - *Gold-Coated Brackets*
    - *Bonding to Crowns and Restorations*
    - *Bonding to Porcelain*
    - *Bonding to Amalgam*
    - *Small Amalgam Filling with Surrounding Sound Enamel*
    - *Large Amalgam Restoration or Amalgam Only*
    - *Bonding to Gold*
    - *Bonding to Composite Restoratives*
    - *Lack of Clinical Relevance in Laboratory Studies on Bonding*
  - Lingual Attachments
  - Ligation of Bonded Brackets
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    - *Clinical Procedure*
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    - *Bracket Removal: Ceramic Brackets*
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  - Amount of Enamel Lost in Debonding
  - Enamel Tearouts
  - Enamel Cracks (Fracture Lines)
  - Adhesive Remnant Wear
  - Reversal of Decalcification
  - Microabrasion
- **Bonded Retainers**
  - Bonded Lingual Canine-to-Canine Retainer Bar
    - *Failure Analysis*
    - *Lingual Retainer Adhesives*
    - *Bonding the 3-3 Retainer Bar*
    - *Long-term Experience*
  - Flexible Spiral Wire Retainers
    - *Advantages and Disadvantages*
    - *Long-term Experience*
    - *Bonding Flexible Spiral Wire Retainer*
    - *Indirect Bonding of Flexible Spiral Wire Retainer*
    - *Repair*
    - *Indications*
    - *Conclusion and Clinical Recommendations*
  - Direct-Bonded Labial Retainers
    - *Technical Procedure*
    - *Long-term Results*
- **Other Applications of Bonding**
  - Bonded Space Maintainers
  - Bonded Single-Tooth Replacements
  - Splinting of Traumatic Injuries
  - Composite Buildups and Porcelain Laminate Veneers

Orthodontists now are approaching 40 years of successful, reliable orthodontic bonding in offices around the world. The median bond failure rate for practitioners in the United States is presently around 5%. The only teeth that were banded routinely by a majority of U.S. orthodontists in a recent survey were the maxillary first molars, and all molars and premolars were banded less routinely than in the past.[1] The prevailing concepts are challenged continuously by new developments and technical improvements.

Achieving a low bond failure rate should be a high-priority objective, since replacing loose brackets is inefficient, time-consuming, and costly. Consequently, a continuous search is on for higher bond strengths, better adhesives, simpler procedures, and materials that will bond in the presence of saliva. However, most bond

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failures result from inconsistencies in the bonding technique and not because of the bonding resins, inadequate bond strengths, or quality of the brackets being used.[2] Newer resin systems and alternative methods to bond to enamel may be giving the false impression that one need not be so careful with the bonding procedures as before.

The basis for the adhesion of brackets to enamel has been enamel etching with phosphoric acid, as first proposed by Buonocore[3] in 1955. In the early 1970s a considerable number of preliminary reports were published on different commercially available direct and indirect bonding systems. The first detailed posttreatment evaluation of direct bonding over a full period of orthodontic treatment in a large sample of patients was published in 1977.[4] Since then, product development in terms of adhesive resins, brackets, and technical details has occurred at a rapid rate. In fact, the progress has made it difficult for the practicing orthodontist to remain properly oriented.

The purpose of this chapter is to update the current available information on bonding to natural and artificial teeth. Further developments are likely to produce significant changes in several of the ideas, clinical suggestions, and even principles presented. Therefore, the main emphasis in this chapter is on clinical aspects. Attempts are made to analyze important factors and offer advice (based on the authors' own clinical and research experience and the results published by others) to help make the bonding of attachments and retainers efficient and trouble free.

To help organize the contents, the chapter is divided into four parts:

1. Bracket bonding
2. Debonding
3. Bonded retainers
4. Other applications of bonding

BRACKET BONDING

The simplicity of bonding can be misleading. The technique undoubtedly can be misused, not only by an inexperienced clinician but also by more experienced orthodontists who do not perform procedures with care. Success in bonding requires understanding of and adherence to accepted orthodontic and preventive dentistry principles.

The advantages and disadvantages of bonding versus banding of different teeth must be weighed according to each practitioner's preferences, skill, and experience. Bonding should be considered as part of a modern preventive package that also includes a strict oral hygiene program, fluoride supplementation, and the use of simple yet effective appliances. In other words, complicated mechanics with abundant use of coil springs and multilooped arches lends itself less well to bonding and easily can compromise the integrity of tooth enamel and gingival tissues around brackets on small bonding bases.

Bonding Procedure

The steps involved in direct and indirect bracket bonding on facial or lingual surfaces are as follows:

- Cleaning
- Enamel conditioning
- Sealing
- Bonding

Cleaning. Cleaning of the teeth with pumice removes plaque and the organic pellicle that normally covers all teeth. One must exercise care to avoid traumatizing the gingival margin and initiating bleeding on teeth that are not fully erupted.

The need for conventional pumice polishing before acid etching has been questioned. However, pumice prophylaxis does not appear to affect the bonding procedure adversely, and cleaning the tooth may be advisable to remove plaque and debris that otherwise might remain trapped at the enamel–resin interface after bonding.

Enamel Conditioning

Moisture Control. After the rinse, salivary control and maintenance of a dry working field is essential. Many devices on the market accomplish this:

- Lip expanders and cheek retractors
- Saliva ejectors
- Tongue guards with bite blocks
- Salivary duct obstructors
- Gadgets that combine several of these
- Cotton or gauze rolls
- Antisialagogues

These products are being improved continually, and the clinician must decide which ones work best. For simultaneous molar-to-molar bonding in both arches, a technique using lip expanders, Dri-Angles (to restrict the flow of saliva from the parotid duct), and saliva ejectors works well.

Present experience indicates that antisialagogues generally are not needed for most patients. When indicated, methantheline (Banthine) tablets (50 mg per 100 lb [45 kg] body weight) in a sugar-free drink, 15 minutes before bonding, may provide adequate results.

Enamel Pretreatment. After the operative field has been isolated, the conditioning solution or gel is applied over the enamel surface for 15 to 30 seconds (see the following discussion). When etching solutions are used, the surface may be kept moist by repeated applications.

At the end of the etching period, the etchant is rinsed off the teeth with abundant water spray. A high-speed evacuator is strongly recommended for increased efficiency in collecting the etchant-water rinse and to reduce moisture contamination on teeth and Dri-Angles. Salivary contamination of the etched surface must not be allowed. (If contamination occurs, rinse with the water spray or re-etch for a few seconds; the patient must not rinse.)

Next, the teeth are dried thoroughly with a moisture-and-oil–free air source to obtain the well-known dull, frosty appearance (Figure 21-1, *A*). Teeth that do not appear dull and frosty white should be re-etched. Cervical enamel, because of its different morphology, usually looks somewhat different from the center and incisal portions of a sufficiently etched tooth (Figure 21-1, *B*). The cervical enamel should not be re-etched in attempts to produce a uniform appearance over the entire enamel surface.

This procedure probably reflects the general use of acid etching in orthodontics. However, considerable discussion of and continuous debate over several aspects of enamel pretreatment remain:

1. Should the etch cover the entire facial enamel or only a small portion outside the bracket pad?
2. Are gels preferable to solutions?
3. What is the optimal etching time? Is it different for young and old teeth?
4. Is sandblasting as effective as acid etching?
5. What is the preferred procedure for deciduous teeth?
6. Is prolonged etching necessary when teeth are pretreated with fluoride?
7. Will incorporation of fluorides in the etching solution increase the resistance of enamel to caries attack?
8. Is etching permissible on teeth with internal white spots? Or is it more likely that the etchant will open up underlying demineralized areas?

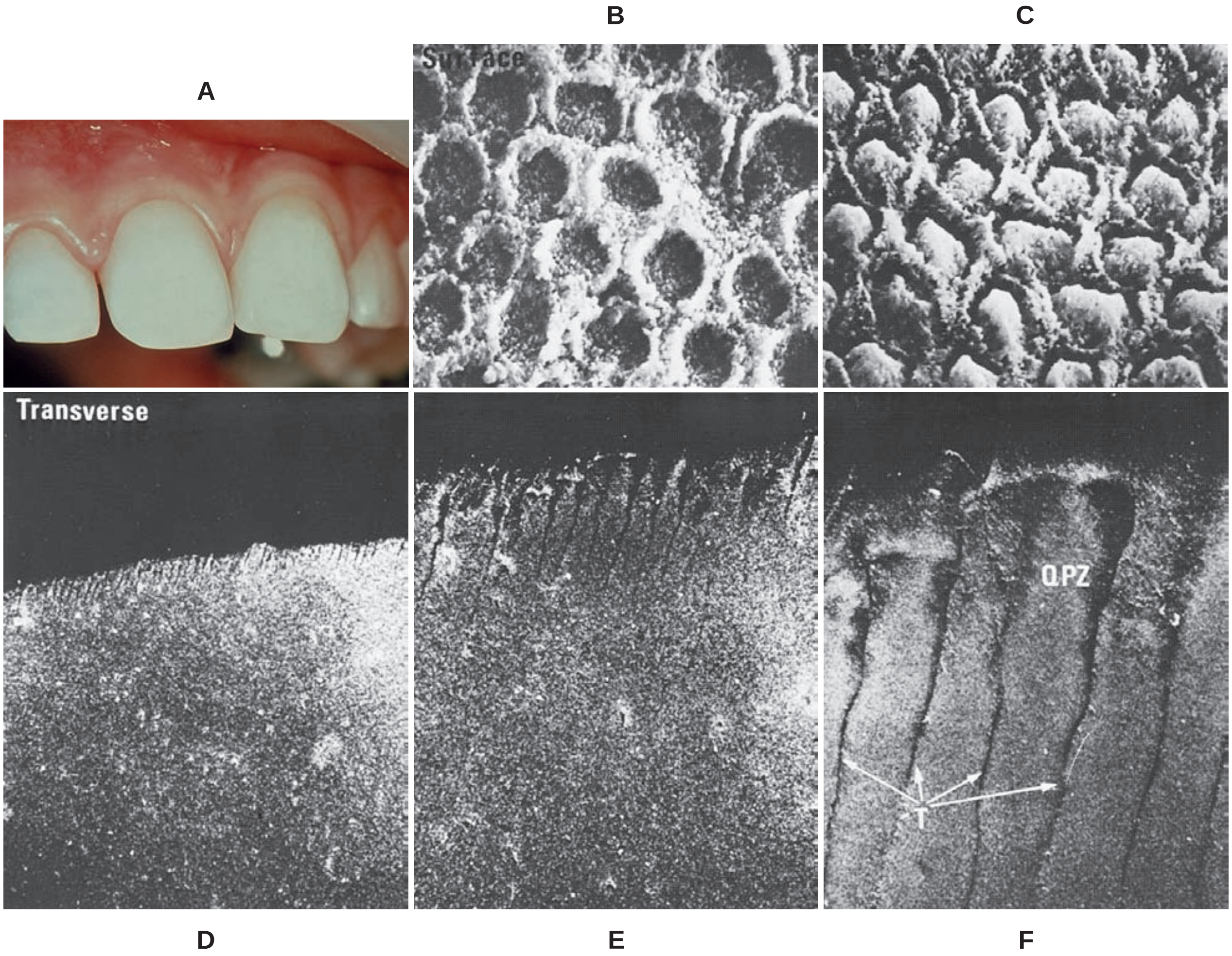

FIGURE 21-1 Acid-etch conditioning of enamel before bracket bonding. **A,** Frosty white appearance. **B, C,** Scanning electron micrograph of an enamel surface that has been etched with 37% phosphoric acid. (In **B** the prism centers have been removed preferentially, whereas in **C** the loss of prism peripheries demonstrates the head-and-tail arrangement of the prisms.) **D–F,** Transverse section of an etched porous enamel surface showing two distinct zones, the qualitative porous zone (QPZ) and the quantitative porous zone. In the latter, an even row of resin tags (*T*) may penetrate.

9. How much enamel is removed by etching, and how deep are the histologic alterations? Are they reversible? Is etching harmful?
10. Should means other than acid etching with phosphoric acid (e.g., polyacrylic acid, maleic acid, or self-etching primers) be preferred?

Although these questions are of considerable theoretical interest, most debate concerning acid etching appears to be of limited clinical significance, at least as it bears on bond strength. In other words, good bond strength apparently depends much more on (1) avoiding moisture contamination and (2) achieving undisturbed setting of the bonding adhesive than on variations in the etching procedures.

Some short answers to the foregoing questions are as follows:

1. Although it may seem logical to etch an area only slightly larger than the pad, clinical experience over more than 25 years indicates that etching the entire facial enamel with solution is harmless—at least when a fluoride mouth rinse is used regularly.
2. No apparent difference exists in the degree of surface irregularity after etching with an acid solution compared with etching with an acid gel. Gels provide better control for restricting the etched area but may require more thorough rinsing afterward. The most popular enamel/dentin etchant in general dentistry is the Ultraetch 35% phosphoric acid blue gel (Ultradent Products, South Jordan, UT). This gel is dispensed by syringe; has adequate color contrast, smooth consistency, and almost ideal viscosity for application and rinsing off cleanly; and provides an even, nicely demarcated white frosted appearance. This etchant is recommended whenever extra good etching of enamel is desired, such as for deciduous teeth, for rebonding brackets, and for bonded retainers (see Figure 21-35 later).
3. Studies and clinical experience indicate that 15 to 30 seconds is probably adequate for etching most young permanent teeth. However, important individual variation exists in enamel solubility between patients, between teeth, and within the same tooth. One benefit of conventional acid etching is that it tends to neutralize the differences between individuals and between teeth. Thus, a phosphoric acid etch of sufficient time can compensate for those individuals whose enamel is more acid resistant. Attempts to use materials that produce a minimal etch—such as glass ionomers, hybrid resin glass ionomers, and the newer self-etching primers—appear to result in increased clinical bond failure rates.
4. Sandblasting without acid etching produces lower bond strengths than acid etching and consistently results in bond failures at the enamel–adhesive interface. Sandblasting followed by acid etching produces bond strengths comparable to or higher than acid-etched enamel.
5. A recommended procedure for conditioning deciduous teeth is to sandblast with 50 microns of aluminum oxide for 3 seconds to remove some outermost aprismatic enamel and then etch for 30 seconds with the Ultraetch 35% phosphoric acid gel. The failure rate with this procedure for the authors is less than 5%.
6. Clinical and laboratory experience indicates that extra etching time is not necessary when teeth have been pretreated with fluoride. When in doubt, check that the enamel looks uniformly dull and frosty white after the etch; if it does, surface retention is adequate for bonding.
7. Fluoridated phosphoric acid solutions and gels provide an overall morphologic etching effect similar to nonfluoridated ones and give adequate bond strength in direct-bonding procedures. Further studies are needed to determine their effectiveness regarding caries protection around brackets over a full period of orthodontic treatment.
8. One should exercise caution when etching over acquired and developmental demineralizations. The procedure is best avoided. If this is impossible, a short etching time, the application of sealant or primer, and the use of direct bonding with extra attention to not having areas of adhesive deficiency are important. The presence of voids, together with poor hygiene, can lead to metal corrosion and indelible staining of underlying developmental white spots.
9. A routine etching removes from 3 to 10 microns of surface enamel. Another 25 microns reveals subtle histologic alterations, creating the necessary mechanical interlocks (see Figure 21-1). Deeper localized dissolutions generally cause penetration to a depth of about 100 microns or more. Although laboratory studies indicate that the enamel alterations are largely (though not completely) reversible, the overall effect of applying etchant to healthy enamel is not detrimental. This point is augmented by the fact that normally enamel is from 1000 to 2000 microns thick (except as it tapers toward the cervical margin), abrasive wear of facial enamel is normal and proceeds at a rate of up to 2 mm per year, and facial surfaces are self-cleaning and not prone to caries.[5]
10. Use of polyacrylic acid with residual sulfate is reported to provide retention areas in enamel similar to those after phosphoric acid etching with less risk of enamel damage at debonding. However, other researchers have found much weaker bonds. The same is true for the use of maleic acid.

Sealant, Primers. After the teeth are completely dry and frosty white, a thin layer of bonding agent (sealant, primer) may be painted over the etched enamel surface. The coating may be thinned by a gentle air burst for 1 to 2 seconds. Bracket placement should be started immediately after all etched surfaces are coated.

Much confusion and uncertainty surround the use of sealants and primers in orthodontic bonding. Research has been devoted to determining the exact function of the intermediate resin in the acid-etch procedure. The findings are divergent. Some investigators conclude that an intermediate resin is necessary to achieve proper bond strength; some indicate that intermediate resin is necessary to improve resistance to microleakage; others feel intermediate resin is necessary for both reasons; still others do not think that the intermediate resin is necessary at all.

A particular problem in orthodontics is that the sealant film on a facial tooth surface is so thin that oxygen inhibition of polymerization is likely to occur with autopolymerizing sealants. With acetone-containing and light-polymerized sealants, nonpolymerization seems less of a problem.

Why then should a sealant be of any value in bracket bonding? If nothing else, sealant permits a relaxation of moisture control because this is no longer critical after resin coating. Sealants also provide enamel cover in areas of adhesive voids, which is probably especially valuable with indirect bonding. The caries protection of sealant around the bracket base is more uncertain, and further studies are needed on the clinical merits of fluoride-containing sealants.

Moisture-Insensitive Primers. In an attempt to reduce the bond failure rates under moisture contaminations, hydrophilic primers that can bond in wet fields (Transbond MIP, 3M/Unitek, Monrovia, California; and Assure, Reliance Orthodontics, Itasca, Illinois) have been introduced as a potential solution. Laboratory studies investigating the effect of saliva contamination on bond strength show conflicting results.[6–8] Although bond strengths were significantly lower under wet conditions than in dry conditions, the hydrophilic primers may be suitable in difficult moisture-control situations. This may be the case in some instances of second molar bonding and when there is risk for blood contamination on half erupted teeth and on impacted canines. For optimal results, the moisture-insensitive primers should be used with their respective adhesive resins.

The hydrophilic resin sealants or primers polymerize in the presence of a slight amount of water, but they will not compensate routinely for saliva contamination. When bonding to enamel, one must place the resin sealant or resin primer onto the prepared enamel before the pellicle (biofilm) from the saliva. This is not particularly difficult but is crucial to a successful enamel bond.[46]

Self-Etching Primers. Combining conditioning and priming into one step may result in improvement in time and cost-effectiveness for clinicians and patients, provided the clinical bond failure rates are not increased significantly. The main feature of the single-step etch/primer bonding systems is that no separate acid etching of the enamel and subsequent rinsing with water and air spray is required; the liquid itself has a component that conditions the enamel surface. The active ingredient of the self-etching primers (SEPs) is a methacrylated phosphoric acid ester that dissolves calcium from hydroxyapatite. Rather than being rinsed away, the removed calcium forms a complex and is incorporated into the network when the primer polymerizes. Etching and monomer penetration to the exposed enamel rods are simultaneous, and the depth of etch and primer penetration are identical.

Three mechanisms act to stop the etching process. First, the acid groups attached to the monomer are neutralized by forming a complex with calcium from hydroxyapatite. Second, as the solvent is driven from the primer during the airburst step, the viscosity rises, slowing the transport of acid groups to the enamel interface. Finally, as the primer is light cured and the primer monomers are polymerized, transport of acid groups to the interface is stopped. Scanning electron microscopy examination of the impression of SEP-treated enamel shows different surface characteristics from acid-etched enamel (Figure 21-2, *B, C*). Instead of the well-known distinct honeycombed structure with microtag and macrotag formation (Figure 21-2, *A*), one finds an irregular but smooth hybrid layer, 3 to 4 microns thick, and irregular tag formation with no apparent indentations of enamel prism or core material. The minimal etch obtained with the SEPs indicates that the majority of the bond may be more of a chemical bond with the calcium in the enamel than the mechanical bond achieved with a conventional phosphoric acid etch.[46]

Clinical procedure: For optimal bonding with the SEP Transbond Plus (3M/Unitek), the authors recommend the following sequence (Figure 21-3):

1. Dry the tooth surface.
2. Apply Transbond Plus. The single-use package consists of three compartments. The first compartment contains methacrylated phosphoric acid esters, photosensitizers, and stabilizers. The second compartment contains water and soluble fluoride. The third compartment contains an applicator microbrush (Figure 21-3, *A, B*). Squeezing and folding the first compartment over to the second activates the system. The mixed component then is ejected to the third to wet the applicator tip. Stay on the tooth surface to avoid gingival irritation. Rub thoroughly for at least 3 seconds and always wet the surface with new solution to ensure the monomer penetration (Figure 21-3, *C, D*). The presence of water in the chemical composition of Transbond Plus may necessitate air drying, but as the operator moves from one side to the other, the solvent evaporates and drying is no longer necessary.

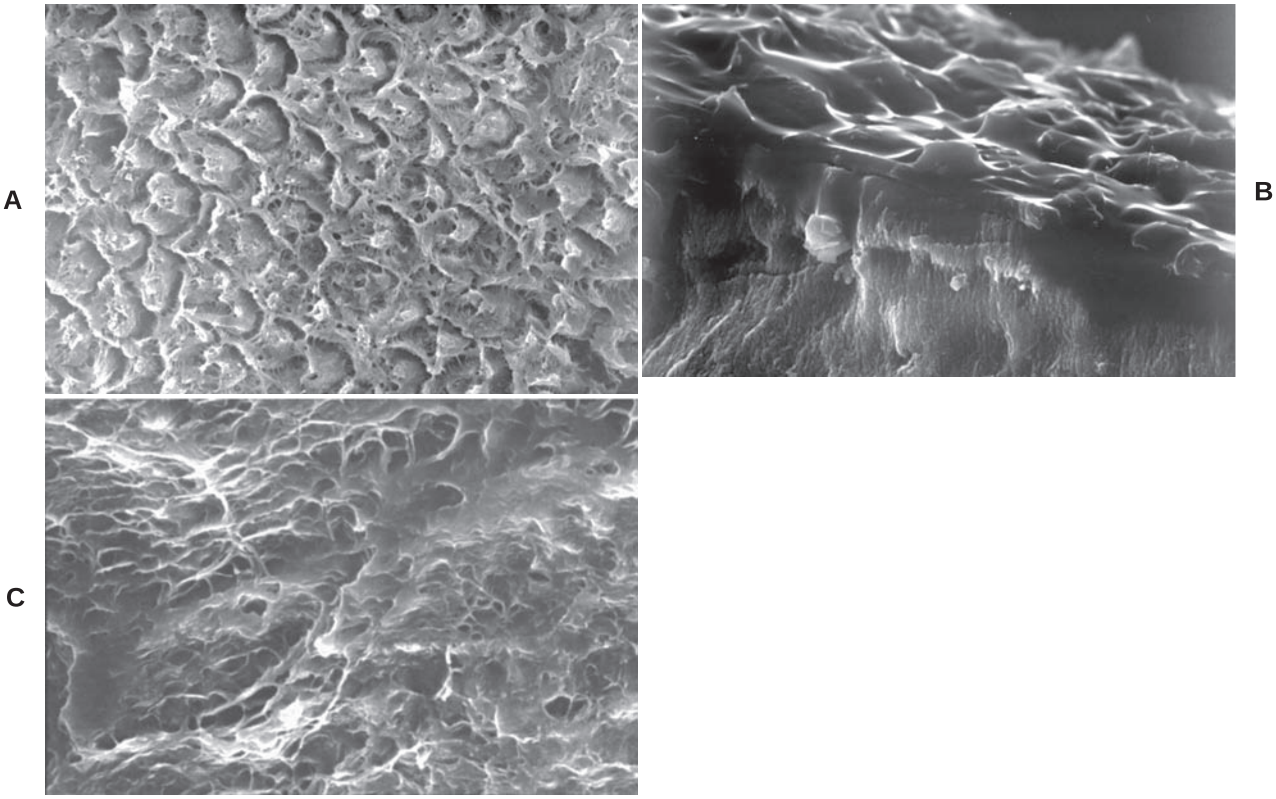

FIGURE 21-2 Comparison of scanning electron microscopy views of adhesive under the bracket base after phosphoric acid etching and use of self-etching primer (Transbond Plus). **A,** Adhesive under the bracket base after removal of phosphoric acid–etched enamel. Note exact replica of honeycomb appearance (×1500). **B,** Cross section showing Transbond Plus–treated enamel and outer surface of Transbond Plus layer on enamel (×2000). **C,** Adhesive under the bracket base after complete removal of the Transbond Plus–treated enamel (×1500).

3. Bond the bracket with Transbond XT (3M/Unitek) and cure with light.

The use of the new SEPs for orthodontic purposes has not yet been evaluated fully. Recent laboratory studies[9] indicate that the shear bond strength of mix (Transbond Plus) and no-mix (Ideal 1, GAC International, Bohemia, NY) SEPs were not significantly different from one another. In a prospective clinical trial, significantly fewer bracket bond failures were found with Transbond Plus than with Ideal 1 SEP system over an 18-month period.[10] Clinical bond strengths using SEPs may appear to be lower than those with conventional etching and priming.[11] The author's experience since 2001 with more than 2300 attachments on 106 patients indicates a reasonably low failure rate (4.1%), which is significantly higher than that for conventional phosphoric acid etching. Debonding brackets after SEP application also is easier and requires shorter time to remove the adhesive compared with acid etching. However, there is not enough information on the effect of SEP application on enamel resistance against demineralizations. A recent in vitro study, using confocal microscopy, showed that the SEP provided no resistance to enamel demineralizations.[12] In a follow-up clinical study, comparing the SEP and the conventional etch-sealant system, twice as many white spot lesions were found in the SEP group, especially in patients with poor oral hygiene.[13]

When deciding which etching and priming system to use, each clinician must weigh bond failure rates and reduced resistance to demineralizations against the time saved in bonding and debonding.

Bonding. Immediately after all teeth to be bonded have been painted with sealant or primer, the operator should proceed with the actual bonding of the attachments. At present, the majority of clinicians routinely bond brackets with the direct rather than the indirect technique.[1]

In a 2008 survey in the United States, about 90% of orthodontists routinely were using direct bonding. Indirect bracket bonding was routinely used labially by about 13% and lingually by 4%. About 50% of the U.S. specialists have replaced the chemically cured one- or two-paste adhesives and have adopted the light-initiated bonding resins.[1]

Many different adhesives exist for direct bonding, and new ones appear continuously. However, the basic bonding technique is only slightly modified for varying materials according to each manufacturer's instructions. The easiest method of bonding is to add a slight excess of adhesive to the backing of the attachment (Figure

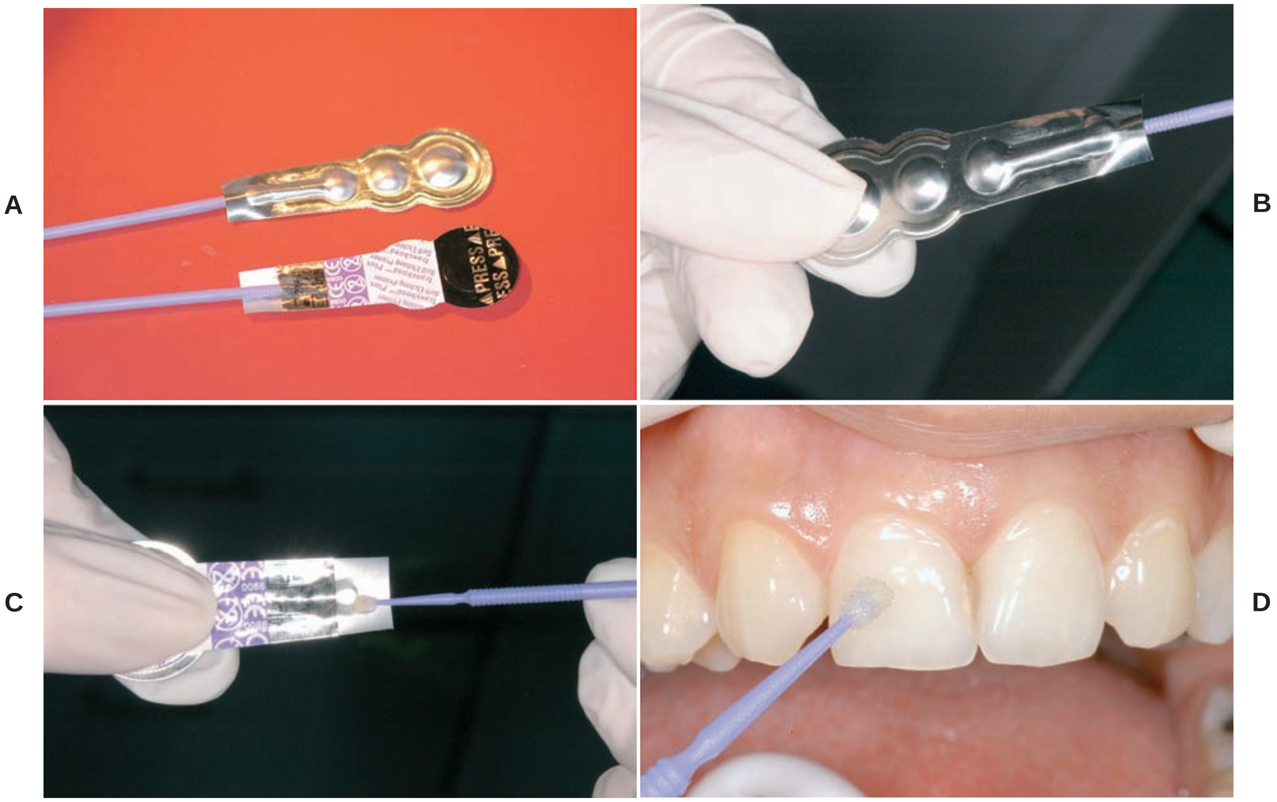

FIGURE 21-3 Application of self-etching primer (Transbond Plus) on enamel surface of maxillary incisor (see text for explanation).

21-4) and then place the attachment on the tooth surface in its correct position.

When bonding attachments one at a time with new adhesive, the operator can work in a relaxed manner and obtain optimal bond strength for each bracket. Hurrying is not necessary because plenty of time is available for placing the bracket in its correct position, checking it, and if necessary repositioning it within the working time of the adhesive or before light curing.

The recommended bracket bonding procedure (with any adhesive) consists of the following steps:

1. Transfer
2. Positioning
3. Fitting
4. Removal of excess

Transfer. The clinician grips the bracket with reverse action tweezers and then applies the mixed adhesive to the back of the bonding base. The clinician immediately places the bracket on the tooth close to its correct position (Figure 21-4, *B*).

Positioning. The clinician uses a placement scaler to position the brackets mesiodistally and incisogingivally and to angulate them accurately relative to the long axis of the teeth. Proper vertical positioning may be enhanced by different measuring devices or height guides.[14] A mouth mirror will aid in horizontal positioning, particularly on rotated premolars (Figure 21-5). Due to human limitations in direct placement of brackets on both anterior and posterior teeth, it is still necessary to use archwire bends or bracket repositioning to compensate for the inherent inaccuracies in bracket positions.[14]

Fitting. Next, the clinician turns the scaler and with one-point contact with the bracket, pushes firmly toward the tooth surface. The tight fit will result in good bond strength, little material to remove on debonding, optimal adhesive penetration into bracket backing, and reduced slide when excess material extrudes peripherally. The clinician should remove the scaler after the bracket is in the correct position and should make no attempts to hold the bracket in place with the instrument. Even slight movement may disturb the setting of the adhesive. Totally undisturbed setting is essential for achieving adequate bond strength.

Removal of Excess. A slight bit of excess adhesive is essential to minimize the possibility of voids and to be certain that the adhesive will be buttered into the bracket backing when the bracket is being fitted. The excess is particularly helpful on teeth with abnormal morphology. Excess adhesive will not be worn away by toothbrushing and other mechanical forces; it must be removed (especially along the gingival margin) with the scaler before

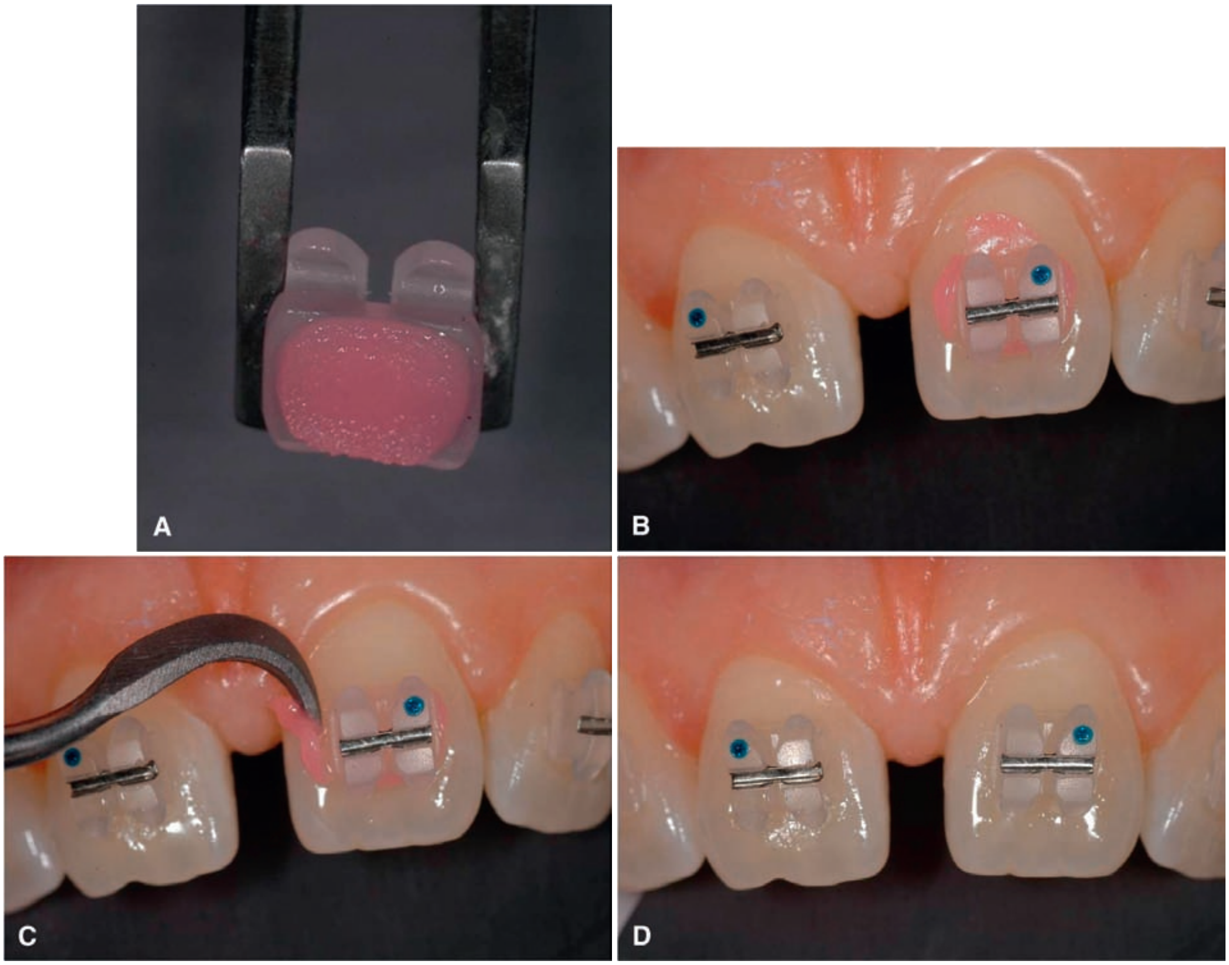

FIGURE 21-4 Direct bracket bonding with light-cured color-change adhesive resin. **A,** Adhesive resin on contact surface of bracket. **B,** Bracket transferred to tooth surface and oriented with placement scaler. **C,** Excess adhesive (*red color*) is removed with the scaler before light-activation. **D,** No color of adhesive resin after curing.

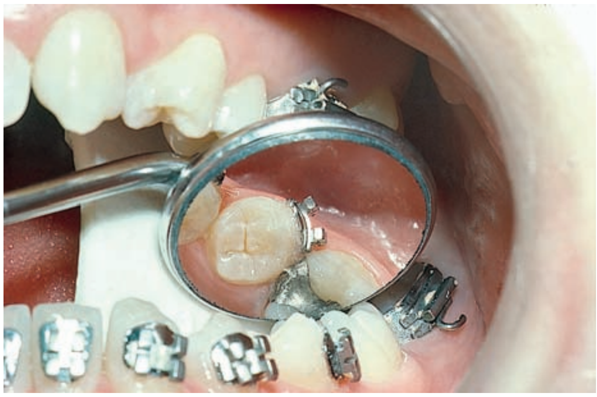

FIGURE 21-5 Bracket position on difficult teeth may be checked with a mouth mirror.

the adhesive has set (see Figure 21-4, *C*) or with burs after setting (Figure 21-6).

Most important is to remove the excess adhesive to prevent or minimize gingival irritation and plaque buildup around the periphery of the bonding base (see Figures 21-4 and 21-6). Removal of excess adhesive reduces periodontal damage and the possibility of decalcification. Clinically significant gingival hyperplasia and inflammation rapidly occur when excess adhesive comes close to the gingiva and is not removed properly. In addition, removal of excess adhesive can improve aesthetics not only by providing a neater and cleaner appearance but also by eliminating exposed adhesive that might become discolored in the oral environment.

When the procedure just described has been repeated for every bracket to be bonded, the clinician carefully checks the position of each bracket (see Figure 21-5). Any attachment that is not in good position should be removed with pliers and rebonded immediately. After inserting a leveling archwire, the clinician instructs the patient how to brush properly around the brackets and archwires and gives a program of daily fluoride mouth rinses (0.05% NaF) to follow.

Bonding to Premolars. The most difficult technical problem for bonding to maxillary first and second premolars is to obtain accurate bracket placement. The

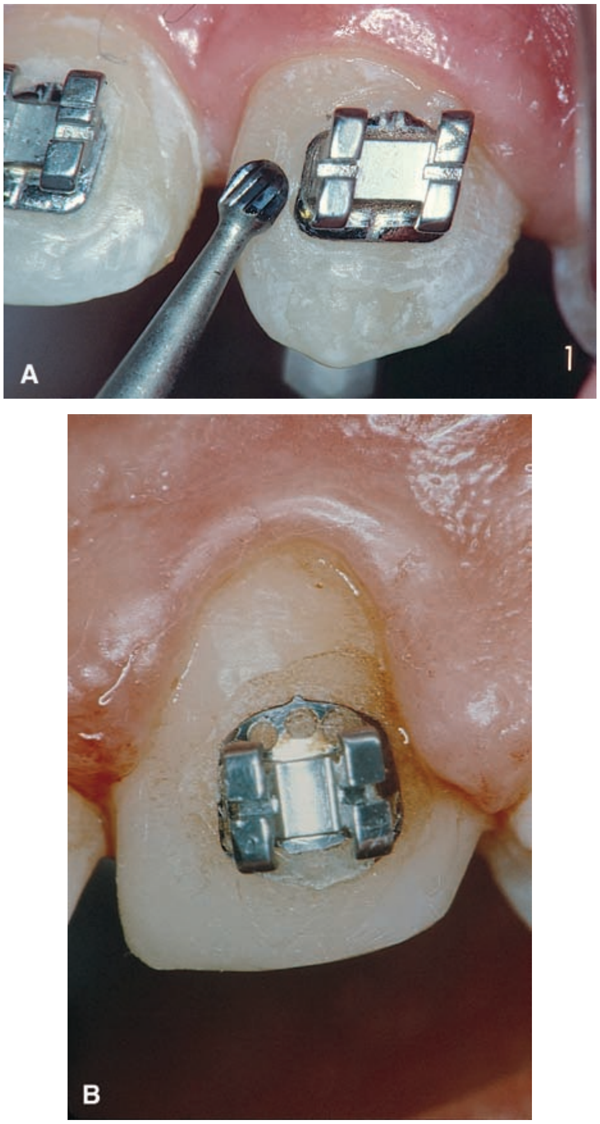

FIGURE 21-6 **A,** Use of a large (No. 7006) oval tungsten carbide bur for removal of set adhesive around the bracket base. **B,** Relationship between excess adhesive and gingival inflammation. Note the hyperplastic gingival changes on the distal aspect, where excess adhesive is close to the gingival margin. Less reaction occurs on the mesial aspects, where adhesive is farther from the gingiva.

visibility for direct bonding is facilitated if these teeth are bonded without a lip expander, one side at a time.

For newly erupted mandibular premolars, gingivally offset brackets are recommended. The gingival third of these teeth may have a high incidence of aprismatic enamel and an enamel rod direction that is less retentive of resin tags.

Bonding to Molars. With the difficulty of banding in young patients, particularly second molars, bonding these and other molars is advantageous. With special technique and care, the routine bonding of first, second, and third molars can be accomplished with high success rates.

Resin-modified glass ionomer cements (chemical and light cured) have a disadvantage when bonding molar attachments. The liquid contains polyacrylic and maleic acids, which will not create micromechanical retention as well as 37% phosphoric acid does. The bond strength with resin-modified glass ionomer cements is significantly lower than that of composite resins after phosphoric acid etching.

For optimal bond strength, it appears preferable to establish adequate moisture control and bond molar attachments with conventional bisphenol A diglycidyl dimethacrylate (bis-GMA) composite resins.

Types of Adhesives

Two basic types of dental resins may be used for orthodontic bracket bonding. Both are polymers and are classified as acrylic or diacrylate resins. Both types of adhesive exist in filled or unfilled forms. The acrylic resins are based on self-curing acrylics and consist of methylmethacrylate monomer and ultrafine powder. Most diacrylate resins are based on the acrylic modified epoxy resin bis-GMA or Bowen's resin. A fundamental difference is that resins of the first type form linear polymers only, whereas those of the second type may be polymerized also by cross-linking into a three-dimensional network. This cross-linking contributes to greater strength, lower water absorption, and less polymerization shrinkage.

A number of independent investigations indicate that the filled diacrylate resins of the bis-GMA type (e.g., Concise [3M, St. Paul, MN] and Phase-II [Reliance Orthodontics]) have the best physical properties and are the strongest adhesives for metal brackets. Acrylic or combination resins have been most successful with plastic brackets. Several alternatives exist to chemically autopolymerizing paste-paste systems.

No-Mix Adhesives. No-mix adhesives set when one paste under light pressure is brought together with a primer fluid on the etched enamel and bracket backing or when another paste on the tooth is to be bonded. Thus, one adhesive component is applied to the bracket base while another is applied to the dried etched tooth. As soon as the bracket is positioned precisely, the orthodontist presses the bracket firmly into place and curing occurs, usually within 30 to 60 seconds.

Although the clinical bonding procedure may be simplified with the no-mix adhesives, little long-term information is available on their bond strengths compared with those of the conventionally mixed paste-paste systems. Furthermore, little is known about how much unpolymerized rest monomer remains in the cured adhesive and its eventual toxicity. The only studies assessing orthodontic adhesives with a protocol that mimics the orthodontic bonding process are those of Eliades et al.[15,16] These authors found no release of bisphenol-A or oestrogenic effect. For now, there is no controversy in the orthodontic community regarding the safety of our most commonly used materials.

Light-Polymerized Adhesives. The desire to cure on demand is driving an increasing number of orthodontic practices to use light-cured adhesives instead of the more traditional paste-paste adhesives requiring in-office mixing.[1] The light-initiated resins by now have become the most popular adhesives for a majority of orthodontists.[1] These resins offer the advantage of extended, though not indefinite, working time. This in turn provides the opportunity for assistants to place the brackets, with the orthodontist following up with any final positioning.

Light-cured resins used with metal brackets are usually dual-cure resins incorporating light initiators and a chemical catalyst. Maximum curing depth of light-activated resins depends on the composition of the composite, the light source, and the exposure time. Bond strengths for light-activated materials is comparable to those of chemically cured composites,[2,17] Light-cured adhesives are particularly useful in situations in which a quick set is required, such as when rebonding one loose bracket or when placing an attachment on an impacted canine after surgical uncovering, with the risk for bleeding. But light-cured adhesives are also advantageous when extra-long working time is desirable. This may be the case when difficult premolar bracket positions need to be checked and rechecked with a mouth mirror before the bracket placement is considered optimal.

Metallic and ceramic brackets precoated with light-cured composite and stored in suitable containers are practical in use and are becoming increasingly more popular among clinicians.[1] Such brackets have consistent quality of adhesive, reduced flash, reduced waste, improved cross-infection control, and adequate bond strength. Recent innovations include the development of light-activated color-change adhesives (e.g., APC Plus. 3M/Unitek), which help identify excess adhesive for removal during the bonding procedure (see Figure 21-4, *C, D*).

Light Sources. The orthodontist has the following options for light sources:

1. **Conventional and fast halogen lights:** In light-initiated bonding resins, the curing process begins when a photoinitiator is activated. Most photoinitiator systems use camphoroquinone as the absorber, with the absorption maximum in the blue region of the visible light spectrum at a wavelength of 470 nm. Until recently, the most common method of delivering blue light has been halogen-based light-curing units (e.g., Ortholux XT, 3M/Unitek). Halogen bulbs produce light when electric energy heats a small tungsten filament to high temperatures.

   The halogen lights can cure orthodontic composite resins in 20 seconds and light-cured resin-modified glass ionomers in 40 seconds per bracket.[18] This prolonged curing time is inconvenient for the clinician and the patient. Various attempts have been made therefore to enhance the speed of the light-curing process. Fast halogens (e.g., Optilux 501 or Demetron, Kerr, Orange, CA) have significantly higher-intensity output than other current halogen lights, and this is accomplished by using higher-output lamps or using turbo tips that focus the light and concentrate it into a smaller area. By this means, curing times can be reduced to half of the time needed with conventional halogen lights.
2. **Argon lasers:** In the late 1980s, argon lasers promised to reduce the curing times dramatically. Argon lasers produce a highly concentrated beam of light centered around the 480-nm wavelength. In addition, the light is collimated, which results in more consistent power density over distance. One interesting potential of the argon laser is its ability to protect the lased enamel surface against decalcification. Recent studies have shown that argon laser irradiation significantly reduces enamel demineralization around orthodontic brackets.[19,20] Although the curing times could be reduced to 5 seconds for unfilled and 10 seconds for filled resins with argon laser, their use in orthodontics at present is not extensive,[1] probably because of their high cost and poor portability.
3. **Plasma arc lights:** In the mid-1990s, the xenon plasma arc lamp was introduced for high-intensity curing of composite materials in restorative dentistry. This lamp has a tungsten anode and a cathode in a quartz tube filled with xenon gas. When an electric current is passed through xenon, the gas becomes ionized and forms a plasma made up of negatively and positively charged particles and generates an intense white light. Plasma arc lights are contained in base units rather than in guns because of the high voltage used and heat generated. The light guide is stiff because of the gel inside. The white light is filtered to blue wavelengths, with a narrow spectrum between 430 and 490 nm. Whereas the conventional halogen lamps emit light with an energy level of 300 mW, the plasma arc lamp has a much higher peak energy level of 900 mW. The advantage of the high-intensity light is that the amount of light energy needed for polymerization of the composite resin can be delivered in a much shorter time. Recent clinical studies[17] indicate that exposure times of 3 to 5 seconds for metal brackets and even shorter times for ceramic brackets yield similar bond failure rates as for brackets cured with a conventional halogen light for 20 seconds. Therefore, plasma arc lights significantly reduce the curing time of orthodontic brackets without affecting the bond failure rate. The heat generated by the high-intensity lights and the possibility of harming the pulp tissue have been addressed in several publications. The increase in pulpal temperature in orthodontic bonding was significantly higher with conventional

halogen than with LED or plasma arc lights. However, orthodontic bonding with light-curing units did not exceed the critical 5.5°C value for pulpal health.[21]

4. **Light-emitting diodes (LEDs):** The most recent light source category is the LED sources. Light-emitting diodes use junctions of doped semiconductors to generate the light. They have a lifetime of more than 10,000 hours and undergo little degradation of output over this time. Light-emitting diodes require no filters to produce blue light, resist shock and vibration, and take little power to operate. New-generation LEDs with higher-intensity diodes may shorten the curing times further. The Ortholux LED by 3M/Unitek has recommended curing times of 10 seconds for metal and 5 seconds for ceramic brackets.

In conclusion, regarding the use of different light sources and light-initiated adhesives, the authors' studies[22,23] provided the following results:

- The light source and adhesive must be compatible.
- All new light sources cure resins faster than conventional halogen lights.
- Fast halogen sources are more brand specific but generate low heat and are less expensive than plasma lights and LEDs.
- Plasma arc lights offer the shortest curing times but are expensive and generate heat.
- Light-emitting diodes are small, cordless, and quiet; generate minimal heat; and perform favorably compared with conventional and fast halogen sources.

Glass Ionomer Cements. The glass ionomer cements were introduced in 1972, primarily as luting agents and direct restorative material, with unique properties for bonding chemically to enamel and dentin and to stainless steel and being able to release fluoride ions for caries protection. The second-generation water-hardening cements contain the same acids in freeze-dried form or an alternative powdered copolymer of acrylic and maleic acids. The glass ionomer cements were modified to produce dual-cure or hybrid cements (e.g., Fuji Ortho LC, GC America, Alsip, IL).

Glass ionomer and light-cured glass ionomer cements now are used routinely by most orthodontists for cementing bands,[1] because they are stronger than zinc phosphate and polycarboxylate cements, with less demineralization at the end of treatment and adhesion to enamel and metal. The chemical composition and setting reaction among resin ionomer hybrids vary widely. Some hybrids are categorized as modified composites (compomers or polyacid modified composite resins) and others as true resin-modified glass ionomer cements. For bonding of brackets and buccal tubes with resin-modified glass ionomer cements, there are few reports with regard to clinical performance over a substantial time concerning to bond strength and incidence of demineralization. The pretreatment with polyacrylic acid facilitates a chemical bond between the glass ionomer and the enamel and should thus be performed before bracket bonding with glass ionomer. When bond strength is the main criterion for selecting an adhesive, composite resins are recommended. However, the decalcification risk with fixed orthodontic appliances in some patients should not be ignored, and the use of fluoride-releasing cements may have an impact in preventing this phenomenon.

Selection of adhesives for direct bonding among the myriad alternatives available depends largely on what handling characteristics are preferred and on the individual office philosophy regarding delegation. Bond failures, which are failures at the enamel–adhesive interface (adhesive failures), are likely to result from inadequate technique (e.g., inadequate etch or moisture or saliva contamination with the pellicle). Failures in the adhesive–bracket interface (cohesive failures) more likely are caused by moving the bracket during the initial polymerization, applying an excessive load to the bracket while the resin is still polymerizing, or simply using too little pressure when the adhesive resin is pushed into the mesh base of the bracket.

The incidence of cohesive-type bond failures may increase with the adoption of light-initiated bonding adhesives. The polymerization of bonding materials is a chain reaction. The light cannot penetrate entirely under metal brackets. The polymerization only begins at the edges of the bracket base and then continues as a chain reaction. The light-initiated bonding resins under metal brackets may take as long as 3 days to reach maximum polymerization or strength.[2] The set under clear brackets, however, is almost instantaneous.

Brackets

Three types of attachments are presently available for orthodontic bracket bonding: plastic based, ceramic based, and metal (e.g., stainless steel, gold-coated, titanium) based. Of these, most clinicians prefer the metal attachments for routine applications, at least in children.[1]

Plastic Brackets. Plastic attachments are made of polycarbonate and are used mainly for aesthetic reasons. Pure plastic brackets lack strength to resist distortion and breakage, wire slot wear (which leads to loss of tooth control), uptake of water, discoloration, and the need for compatible bonding resins.[24] Such plastic brackets may be useful in minimal-force situations and for treatments of short duration, particularly in adults. New types of reinforced plastic brackets with and without steel slots inserts have been introduced. Steel-slotted plastic brackets are useful as an aesthetic alternative, but added bulk is required to provide adequate strength of the tie-wings.

Ceramic Brackets. Ceramic brackets have become an important though sometimes troublesome part of today's orthodontic practice. Ceramic orthodontic brackets are machined from monocrystalline or polycrystalline aluminum oxide. Theoretically, such brackets should combine the aesthetics of plastic and the reliability of metal brackets.

Ceramic brackets bond to enamel by two different mechanisms: (1) mechanical retention via indentations and undercuts in the base and (2) chemical bonding by means of a silane coupling agent. With mechanical retention, the stress of debonding is generally at the adhesive–bracket interface, whereas the chemical bonding may produce excessive bond strengths, with the stress at debonding shifted toward the enamel–adhesive interface (see Debonding). Chemically cured and light-cured adhesives are useful for ceramic brackets.

However, the pure ceramic brackets that are available show some significant drawbacks:

1. The frictional resistance between orthodontic wire and ceramic brackets is greater and less predictable than it is with steel brackets. This unpredictability makes determining optimal force levels and anchorage control difficult. Ceramic brackets with a steel slot insert to reduce friction (Figure 21-7) are therefore more reliable for clinical purposes.
2. Ceramic brackets are not as durable as steel brackets and are brittle by nature. These brackets may break during orthodontic treatment, particularly when full-size (or close to full-size) stainless steel archwires are used for torquing purposes.
3. Ceramic brackets are harder than steel and rapidly induce enamel wear of any opposing teeth.
4. Ceramic brackets are more difficult to debond than steel brackets, and wing fractures may occur easily during debracketing.[25]
5. The surface is rougher and more porous than that of steel brackets and hence more easily attracts plaque and stain to the surrounding enamel.
6. The added bulk required to provide adequate strength makes oral hygiene more difficult.

Metal Brackets. Metal brackets rely on mechanical retention for bonding, and mesh gauze is the conventional method of providing this retention.[1] Photoetched recessions or machined undercuts are also available.

The area of the base itself is probably not a crucial factor regarding bond strength with mesh-backed brackets. The use of small, less noticeable metal bases helps avoid gingival irritation. For the same reason, the base should be designed to follow the tissue contour along the gingival margin. The base must not be smaller than the bracket wings, however, because of strength reasons and the danger of demineralization around the periphery. The mandibular molar and premolar bracket wings must be kept out of occlusion, or the brackets may come loose

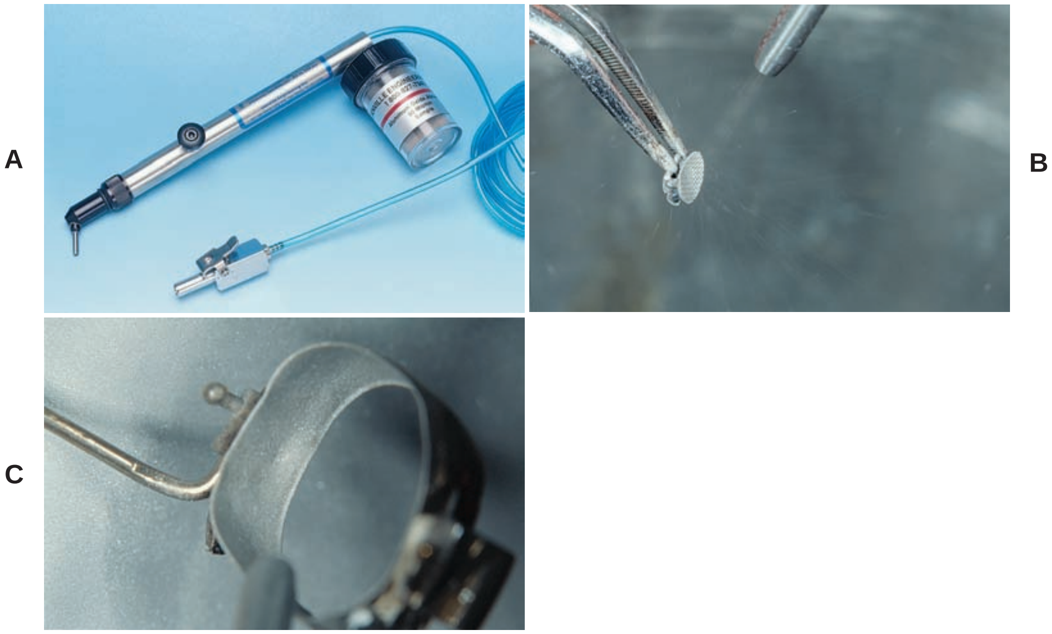

FIGURE 21-7 The Microetcher II is an intraoral sandblaster approved by the U.S. Food and Drug Administration that is most useful for preparing microretentive surfaces in metals and other dental materials, whenever needed. **A,** The appliance consists of a container for the aluminum oxide powder, a pushbutton for fingertip control, and a movable nozzle where the abrasive particles are delivered. The Microetcher is also useful for removing old composite resin and improving the retentive surface of loose brackets before rebonding **(B)** and the inside of the stainless steel molar bands **(C).**

easily. Therefore, before bonding, the operator should do the following:

1. Ask the patient to bite with teeth together; the operator then should evaluate the tooth area available for bonding.
2. Bond mandibular posterior brackets out-of-occlusion, which may necessitate adjustment bends in the archwires.
3. Evaluate any occlusal interference on mandibular posterior attachments immediately after bonding. Occlusal tie-wings in contact with maxillary molar/premolar cusps should be spot ground (with green stone or similar). Using these procedures, the authors have been successful in routinely bonding mandibular molar and premolar attachments in children and adults.

Gold-Coated Brackets. Gold-coated steel brackets (see Figure 21-9 later) have been introduced and have gained some popularity,[1] particularly for maxillary premolars and for mandibular anterior and posterior teeth. The gold-coated brackets may be regarded as an aesthetic improvement over stainless steel attachments, and they are neater and thus more hygienic than ceramic alternatives. Patient acceptance of gold-coated attachments is generally positive.

Bonding to Crowns and Restorations. Many adult patients have crown and bridge restorations fabricated from porcelain and precious metals in addition to amalgam restorations of molars. Banding becomes difficult, if not impossible, on the abutment teeth of fixed bridges. Recent advances in materials and techniques indicate, however, that effective bonding of orthodontic attachments to nonenamel surfaces now may be possible (for review, see Zachrisson[26] and Zachrisson and Büyükyilmaz[27]). Particularly, the Microetcher (Danville Engineering, San Ramon, CA) (see Figure 21-7), which uses 50-micron white or 90-micron tan aluminum oxide particles at about 7 kg/cm^2 pressure, has been advantageous for bonding to different artificial tooth surfaces. This tool is also useful for tasks such as rebonding loose brackets, increasing the retentive area inside molar bands, creating micromechanical retention for bonded retainers, and bonding to deciduous teeth.

Bonding to Porcelain. Orthodontic brackets and retainer wires may have to be fitted to adult patients who have porcelain surfaces on some teeth. Most dental ceramic and metal ceramic crowns, bridges, and veneers presently are made from different feldspathic porcelains containing 10% to 20% aluminum oxide. However, such restorations also can be made from high-aluminous porcelains and glass ceramics.[28]

Several studies have reported that roughening of porcelain and silane treatment may produce in vitro bond strengths that also should be clinically successful; however, these claims have not been verified by clinical investigations or by the authors' experiences. Furthermore, other authors have claimed that the composite-porcelain bond is mostly micromechanical and that the contribution of the silane application for a chemical bond to most feldspathic porcelains is negligible.[29] The clinical effectiveness of single-component liquid silanes, unhydrolyzed (Porcelain Primer, Ormco, Orange, CA) and prehydrolyzed (Scotchprime, 3M), has been questioned.

Cracks or fractures occurring in porcelain crowns or laminate veneers during debonding by machines in laboratory studies may not reflect the clinical situation adequately. In vitro and in vivo bond strengths may differ significantly, and it is possible to debond metal and ceramic brackets clinically much more gently than is done with laboratory machines and to secure an adhesive–bracket separation with all adhesive remaining on the tooth surface.

Therefore, the concept of etching porcelain with hydrofluoric acid to provide an optimally retentive surface is interesting to orthodontists. The most commonly used porcelain etchant is 9.6% hydrofluoric acid in gel form applied for 2 minutes. Hydrofluoric acid is strong and requires bonding separately to other teeth, careful isolation of the working area, cautious removal of gel with cotton roll, rinsing with high-volume suction, and immediate drying and bonding (Figure 21-8). The etchant creates microporosities on the porcelain surface that achieve a mechanical interlock with the composite resin. The etched porcelain will have a frosted appearance similar to that of etched enamel.

One of the reasons why the interpretation of results obtained in laboratory studies on bonding to porcelain is difficult is that rigorous thermocycling of the bonds appears necessary to approximate the clinical reality.[2,29] To be representative, the bond failures must occur in the adhesive interface and not cohesively in one of the materials to the side of the interface.

Even when these requirements are met, the chairside experiences may differ significantly from the laboratory observations. Thus, the authors[28] found that two different techniques—namely, (1) hydrofluoric acid gel treatment and (2) sandblasting and silane (Scotchprime)—produced equally strong bonds in vitro to a feldspathic porcelain. The authors' clinical experience is considerably different. Sandblasting and silane bonds have been found to be unreliable, with unacceptably high failure rates, whereas the hydrofluoric acid gel–conditioned bonds to porcelain have proved to be excellent throughout full routine orthodontic treatment periods (see Figures 21-8 and 21-9). In the authors' hands, the addition of silane (Scotchprime) after sandblasting and hydrofluoric acid treatment did not influence the bond strengths significantly (failure rates of 8.2% versus 8.6%).

For optimal bonding of orthodontic brackets and retainer wires to porcelain surfaces, the following technique is recommended (see Figure 21-8):

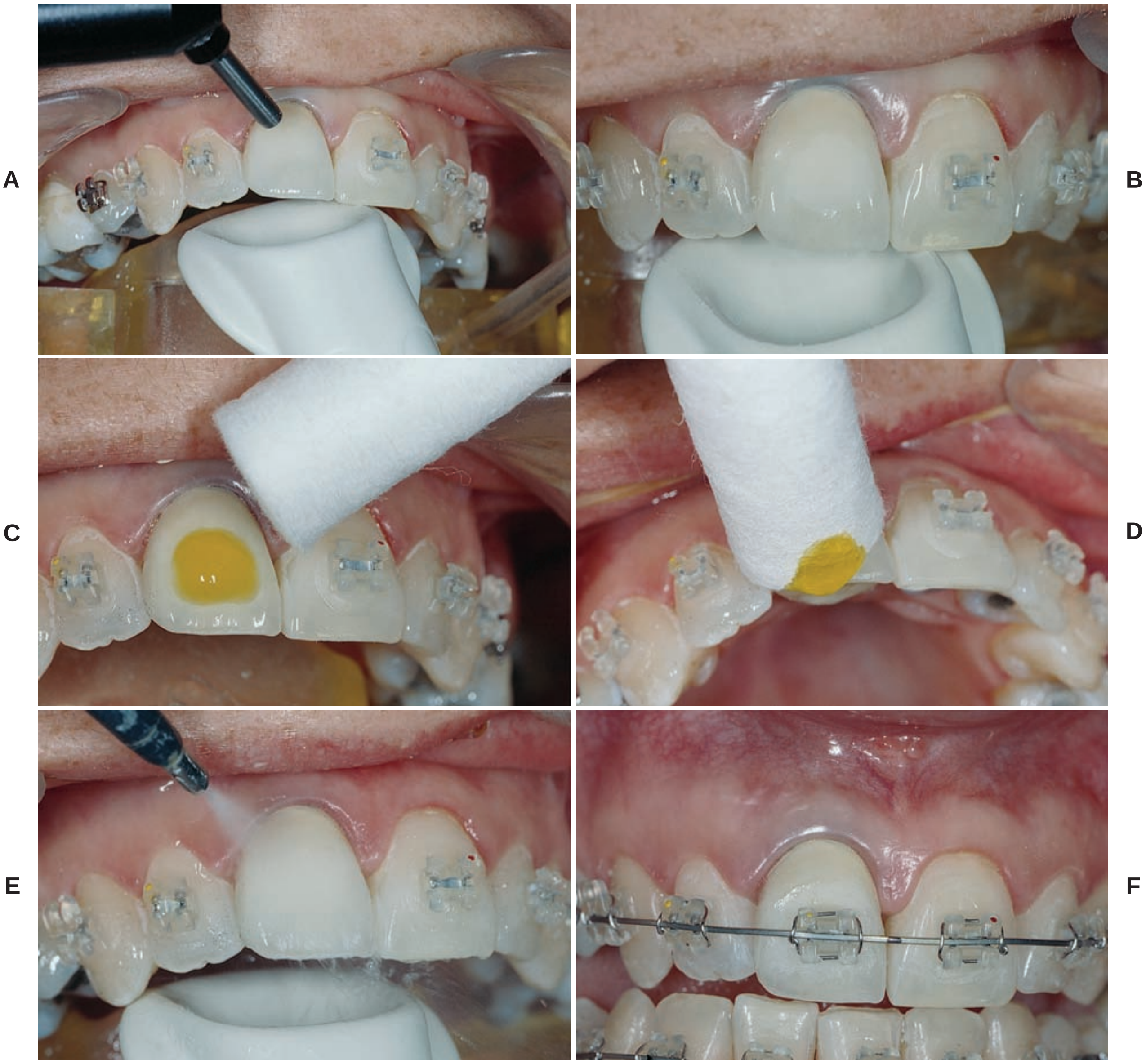

FIGURE 21-8 Technique for bracket bonding to porcelain surfaces includes reliable soft tissue retraction and bonding of the crown separately from other teeth. An area slightly larger than the bracket base is deglazed **(A, B)** before the hydrofluoric acid etching gel is applied for 2 minutes **(C).** The gel is removed with cotton roll **(D),** and the teeth are rinsed with water and air spray under high-volume suction **(E). F,** Final result.

1. Isolate the working field adequately; bond the actual crown separately from the other teeth.
2. Use a barrier gel such as Kool-Dam (Pulpdent, Watertown, MA) (Figure 21-9) on mandibular teeth and whenever a risk exists that the hydrofluoric acid etching gel may flow into contact with the gingiva or soft tissues.
3. Deglaze an area slightly larger than the bracket base by sandblasting with 50 microns of aluminum oxide for 3 seconds.
4. Etch the porcelain with 9.6% hydrofluoric acid gel for 2 minutes.
5. Carefully remove the gel with cotton roll and then rinse using high-volume suction.
6. Immediately dry with air, and bond bracket. The use of a silane is optional.

Hydrofluoric acid will not be effective for bonding to high-alumina porcelains and glass ceramics, and new technique improvements are needed for successful orthodontic bonding to such teeth. A newly introduced alternative technique to the use of hydrofluoric acid gel may be silica coating,[30,31] but further clinical trials are needed to obtain experience with the silica coating technique.

At debonding a gentle technique is necessary to achieve failure at the bracket–adhesive interface and avoid porcelain fracture. A 45-degree outward peripheral force should be applied to the gingival tie-wings of

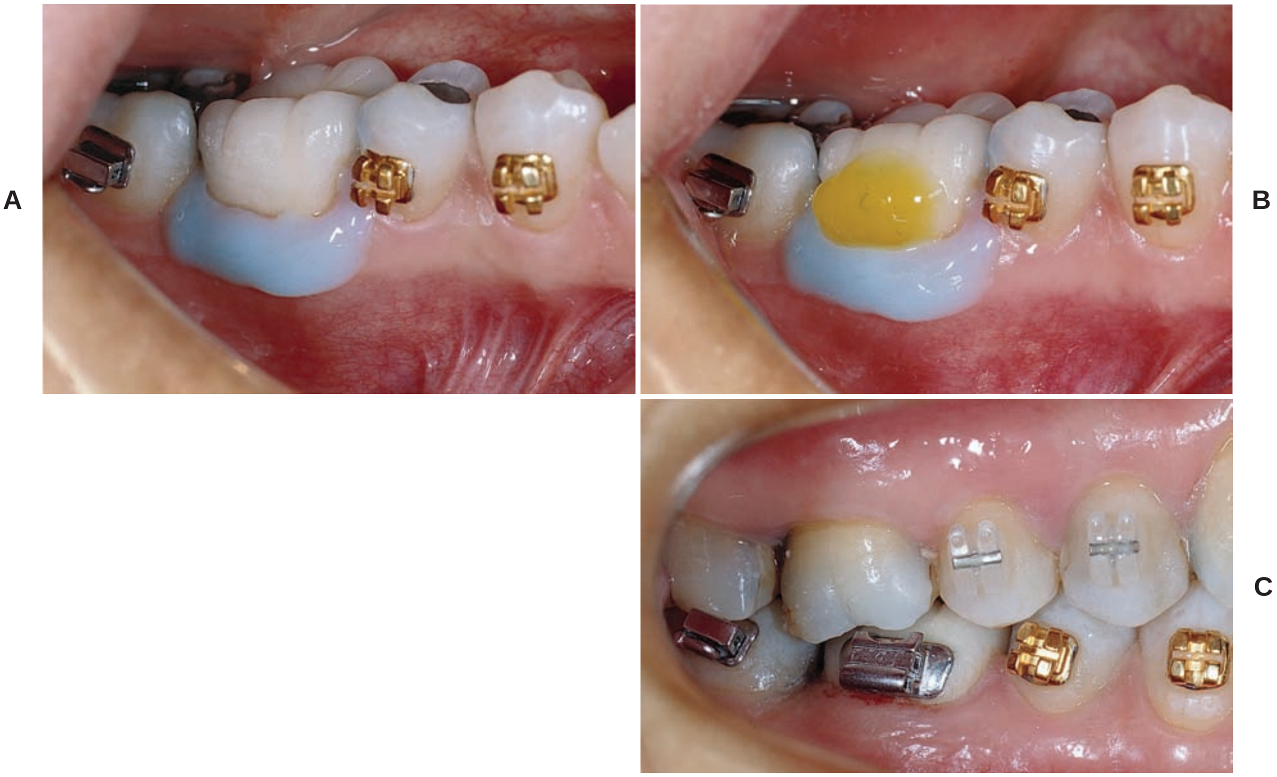

FIGURE 21-9 **A, B,** When hydrofluoric acid gel is used close to the gingival margin, particularly in the mandible, one must use a light-cured blockout resin such as Kool-Dam to protect the soft tissues from the acid. **C,** A lower molar bracket must be positioned out of occlusion with the opposing teeth to avoid bracket loosening. If this is not possible, the tie-wing in contact with the upper molar (usually the distal wing) should be ground with green stone.

twin metal brackets with an anterior bond–removing plier (see Figure 21-17 later) or the wings should be squeezed. The residual adhesive can be removed with a tungsten carbide bur. Ceramic brackets that do not come off easily can be ground away with diamond instruments and adequate cooling. The porcelain surface is restored in a two-step procedure. Smoothing is achieved with slow-speed polishing rubber wheels, whereas enamel-like gloss can be created by application of diamond polishing paste in rubber cups or in specially designed points incorporating such paste.[28]

Bonding to Amalgam. Improved techniques for bonding to amalgam restorations may involve (1) modification of the metal surface (sandblasting, diamond bur roughening [Figures 21-10 and 21-11]), (2) the use of intermediate resins that improve bond strengths (e.g., All-Bond 2 [Bisco, Schaumburg, IL], Enhance, and Metal Primer [Reliance Orthodontics]), and (3) new adhesive resins that bond chemically to nonprecious and precious metals (e.g., 4-methacryloxyethyl trimellitate anhydrid [4-META] resins and 10-MDP bis-GMA resins).[32]

Similar to the bonding to porcelain, apparently a positive correlation does not exist between laboratory and clinical findings when it comes to orthodontic bonding to amalgam fillings. In vitro bonds to amalgam are significantly weaker than for similar brackets bonded to enamel of extracted human teeth.[32,33] However, the clinical performance with different techniques is satisfactory. In the first amalgam study in the authors' laboratory,[32] mean tensile bond strength to sandblasted amalgam tabs ranged from 3.4 to 6.4 MPa, in contrast to control bonds to human enamel of 13.2 MPa. The strongest bonds to amalgam were obtained with a 4-META adhesive (Superbond C&B, Sun Medical, Kyoto, Japan), but an intermediate resin (All-Bond 2) and Concise produced bonds that were comparable to those of Superbond C&B.

A follow-up in vitro study with different intermediate primers on the three main types of dental amalgams (spherical, lathe cut, admixed) showed better results for two 4-META primers (Metal Primer [Reliance Orthodontics], Amalgambond-Plus [Parkell, Farmingdale, NY) than for All-Bond 2.[33] Clinical observations have confirmed these results.

The following procedure is recommended for bonding to amalgam:

Small Amalgam Filling with Surrounding Sound Enamel

1. Sandblast the amalgam alloy with 50 microns of aluminum oxide for 3 seconds (see Figure 21-11, *A*–*C*).

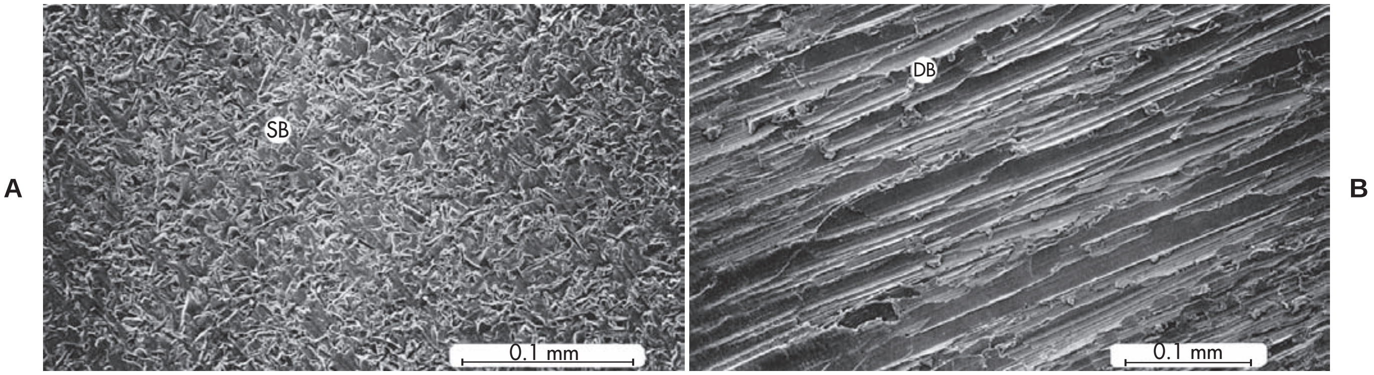

FIGURE 21-10 Scanning electron photomicrographs of a sandblasted **(A)** and diamond bur–roughened **(B)** metal surface. The use of the Microetcher for about 3 seconds (*SB*) provided excellent micromechanical retention, whereas periodic ridges and grooves produced by medium-grit diamond bur (*DB*) have few undercuts for mechanical retention. *Bar,* 0.1 mm.

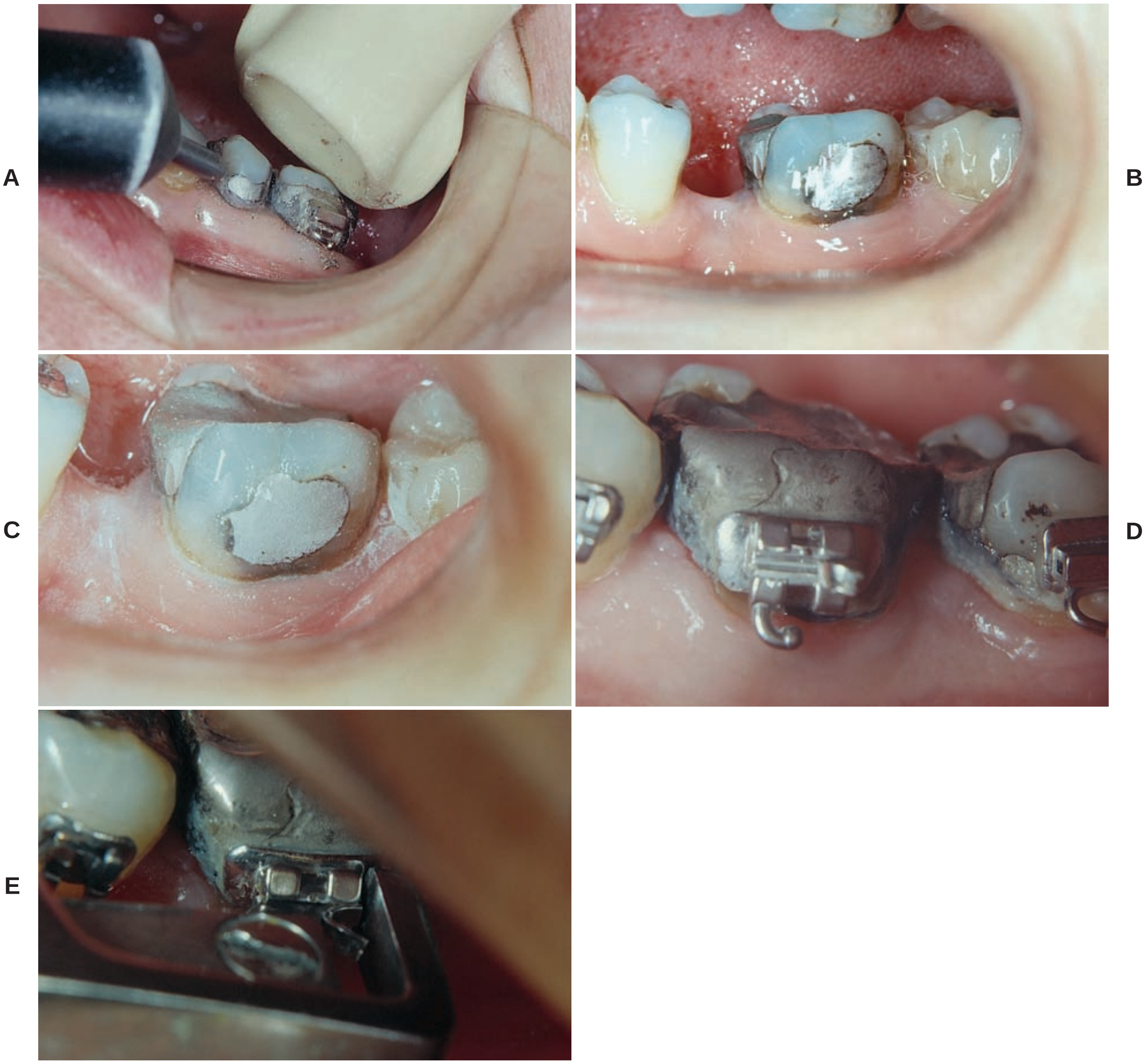

FIGURE 21-11 **A,** During air abrasion, high-velocity evacuation is necessary. **B, C,** Intraoral sandblasting of amalgam restorations produces frosted appearance, indicating increased micromechanical retention (see Figure 14-26, *A*). **D, E,** Convertible cap removal on attachment bonded to amalgam only on mandibular first molar, indicating strength of bond.

2. Condition surrounding enamel with 37% phosphoric acid for 15 seconds.
3. Apply sealant and bond with composite resin. Ensure the bonded attachment is not in occlusion with antagonists.

Large Amalgam Restoration or Amalgam Only (Figure 21-12; see also Figure 21-11)

1. Sandblast the amalgam filling with 50 microns of aluminum oxide for 3 seconds.
2. Apply a uniform coat of Reliance Metal Primer and wait for 30 seconds (or use another comparable primer according to manufacturer's instruction).
3. Apply sealant and bond with composite resin. Ensure the bonded attachment is not in occlusion with antagonists.

Of course, amalgam surfaces can be repolished easily with rubber cups and points after debonding.

Bonding to Gold. In contrast to bonding to porcelain and amalgam, excellent bonding to gold crowns does not yet seem to be available to orthodontic clinicians. This is surprising in light of the high bond strengths, which generally have been reported in different laboratory studies to gold alloys.[34] Different new technologies—including sandblasting, electrolytic tin-plating or plating with gallium-tin solution (Adlloy), the use of several different types of intermediate primer, and new adhesives that bond chemically to precious metals (Superbond C&B, Panavia Ex and Panavia 21 [Kuraray America, New York, NY])[27]—have been reported to improve bonding to gold in laboratory settings. However, the high in vitro bond strengths to gold alloys have not been confirmed by satisfactory clinical results when bonding to gold crowns.

In the authors' experience, even a combination of intraoral sandblasting coupled with the use of All-Bond 2 or 4-META primers and followed by bracket bonding with composite resin or special metal-bonding adhesives may not withstand optimally the occlusal forces in clinical practice. Clinical studies are hampered by the fact that bracket bonding to gold restorations or retainer bonding to lingual metal-ceramic crowns (Figure 21-13, *B*) is not occurring frequently in daily practice.

Bonding to Composite Restoratives. The bond strength obtained with the addition of new composite to mature composite is substantially less than the cohesive strength of the material. However, brackets bonded to a fresh, roughened surface of old composite restorations

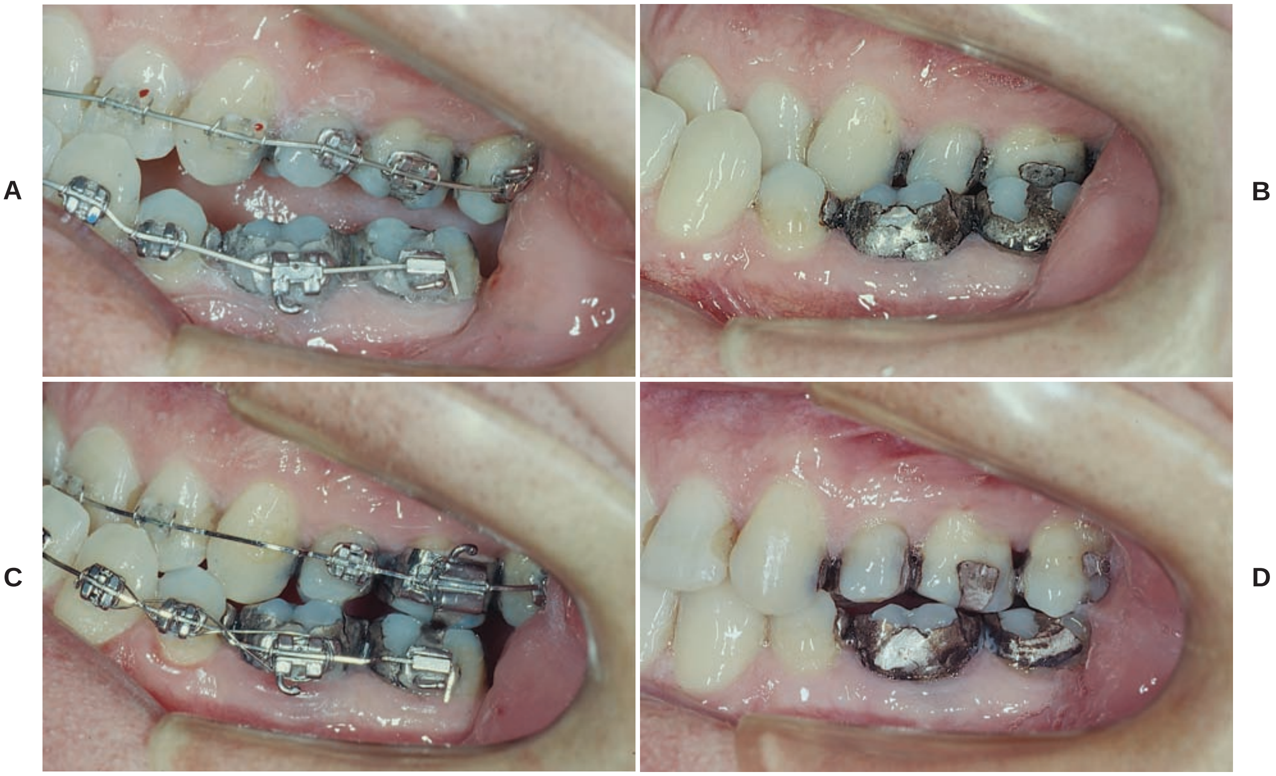

FIGURE 21-12 Orthodontic attachments bonded to large amalgam restorations on maxillary first and mandibular first and second molars in an adult Class III patient before **(A),** during **(B, C),** and after treatment **(D).** Note that superelastic **(B)** and rectangular stainless steel archwires **(C)** were bent over at the distal of the second molar during treatment without coming loose.

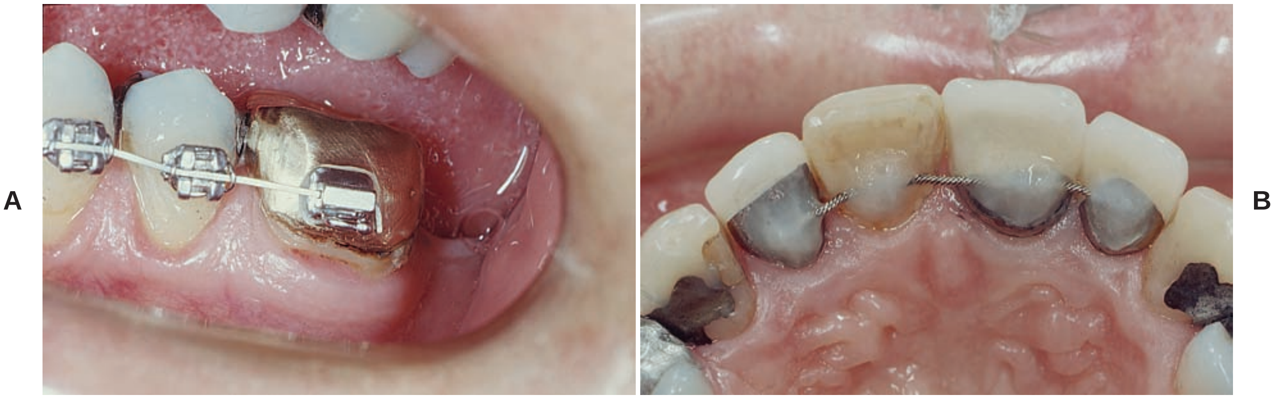

FIGURE 21-13 Bonding to tooth surfaces of gold alloy include bracket bonding to molar crowns **(A)** and retainer wire bonding to the lingual of metal-ceramic crowns (right and left lateral incisors and right central incisor in **B**). If unfilled, 4-methacryloxyethyl trimellitate anhydrid resin is used for retainer bonding; it may be covered with more abrasion-resistant composite resin. *(From Büyükyilmaz T, Zachrisson YØ, Zachrisson BU: Improving orthodontic bonding to gold alloy,* Am J Orthod *108:510, 1995. With permission from the American Association of Orthodontists.)*

appear to be clinically successful in most instances.[35] Use of an intermediate primer is probably advantageous as well.

Lack of Clinical Relevance in Laboratory Studies on Bonding. It follows from the previous statements about bonding to nonenamel tooth surfaces that clinical observations rarely corroborate laboratory findings. Several reasons explain this controversy:

1. *Different type of load:* The debonding force used in most in vitro studies is a continuously increasing load applied to the brackets until they come loose. This load may not be representative for the force applications that occur in the oral cavity.
2. *Different debonding technique:* The easiest and safest method to remove metal bonded brackets clinically is to rely on the low resistance to peel force. By peripheral concentration of the force, the brackets come off at low load levels, with little or no force applied to the tooth. The bonding base will peel from the adhesive, creating a cohesive failure and leaving adhesive on the tooth. Debonding in machines generally is done with pure shear or tensile force applications at much higher loads, and the average stress does not characterize bond strength adequately.
3. *Different environment:* The complex oral environment, with continually changing temperature, stresses, humidity, acidity, and variations in amount and composition of plaque, is not reproducible in the laboratory.

Therefore extrapolations from laboratory to clinical settings on bonding to enamel and nonenamel surfaces should not be made. Laboratory testing is needed primarily to find out which new products are worth testing on patients, but only successful clinical performance of such products over an adequate period of time can provide final proof of efficiency.

Lingual Attachments

A drawback when bonding brackets on the labial surface, compared with banding, is that conventional attachments for control during tooth movement (e.g., cleats, buttons, sheaths, eyelets) are not included. In selected instances such aids may be bonded to the lingual surfaces to supplement the appliance (see Figure 21-33 later).

Because bonded lingual attachments may be swallowed or aspirated if they come loose, cleats are preferred to buttons. Cleats may be closed with an instrument over the elastic module or steel ligature. The bonding of brackets to the lingual surfaces of teeth is discussed separately.

Ligation of Bonded Brackets

In contrast to brackets on bands, bonded brackets will not withstand heavy pull into archwires. Therefore, to learn a few clinical tips on correct ligation is important. Although elastic rings are time saving, they are plaque-attractive to the extent that their use is contraindicated if one aims at excellent oral hygiene and healthy gingival conditions in the patients. Steel ties are safer than elastomers and definitely more hygienic. The rule of thumb in ligation is that the ligature wire should be twisted with the strand that crosses over the archwire closest to the bracket wing (Figure 21-14). This tightens the ligature when the end is tucked under the archwire.

To perform active ligations without pulling off any brackets, the operator should push the archwire into the bottom of the bracket slot using the fingers (for flexible wires) and pliers or ligature director for stiffer wires, and

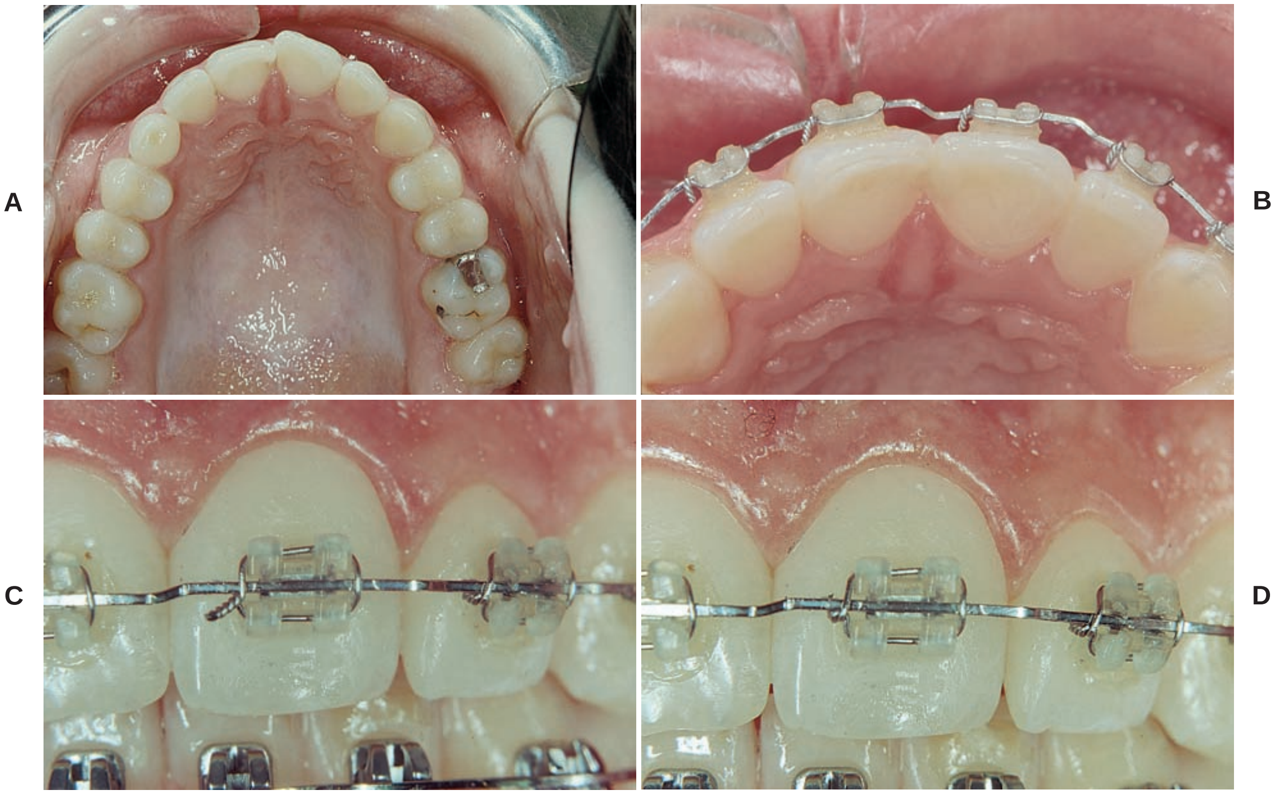

FIGURE 21-14 Technique for active ligation to bonded brackets. **A, B,** A bend in the rectangular archwire is made to correct a contact point in the maxillary anterior region. The archwire is pushed with pliers or finger toward the base of the bracket slot before a passive ligation is made. The ligature wire should be twisted so that the strand that goes over the archwire is closest to the bracket wing **(C, D).** When not complete, the ligature is tightened at the next appointment.

then make a passive ligation. If full engagement is not possible, a partial ligation is made and the ligature can be retied at the next visit, or elastomers can be added.

Several types of ligature-less, self-ligating, low-friction brackets have become available in recent years (e.g., SPEED System [Strite Industries, Cambridge, Ontario], Damon Q [Ormco], In-Ovation C [Dentsply GAC], Smartclip SL3 [3M/Unitek]). The popularity of these brackets seems to be increasing.[1] Such brackets may offer the advantages of saving time, reducing friction, and probably increasing patient comfort. However, tight ligations to secure proper treatment and control of rotations and other tooth positions are more difficult than when steel ties are used with edgewise brackets. Finishing becomes more complicated with self-ligating brackets when detailed archwire bends are made.

Indirect Bonding

Several techniques for indirect bonding are available. In some, the brackets are glued with a temporary material to the teeth on the patient's models, transferred to the mouth with some sort of tray into which the brackets become incorporated, and then bonded simultaneously with a bis-GMA resin. However, most current indirect bonding techniques attach the brackets with composite resin to form a custom base (Figure 21-15). A transfer tray of silicone putty or thermoplastic material is used, and the custom bracket bases are then bonded to the teeth with chemically cured sealant.

The main advantages of indirect compared with direct bonding are that the brackets can be positioned more accurately in the laboratory and the clinical chair time is decreased. However, the method is technique-sensitive, and the chairside procedure is more crucial, at least for inexperienced clinicians; removal of excess adhesive can be more difficult and more time consuming with some techniques; the risk for adhesive deficiencies under the brackets is greater; the risk for adhesive leakage to interproximal gingival areas can disturb oral hygiene procedures; and the failure rates with some methods seem to be slightly higher.[36,37] Only about 13% of orthodontists in the United States use indirect bonding techniques at present.[1]

Reasons for differences in bond strength between direct and indirect bonding techniques, if any, may be as follows: (1) the bracket bases may be fitted closer to the tooth surfaces with one-point fitting by a placement scaler (see Figure 21-4) than when a transfer tray is placed over the teeth, and (2) a totally undisturbed

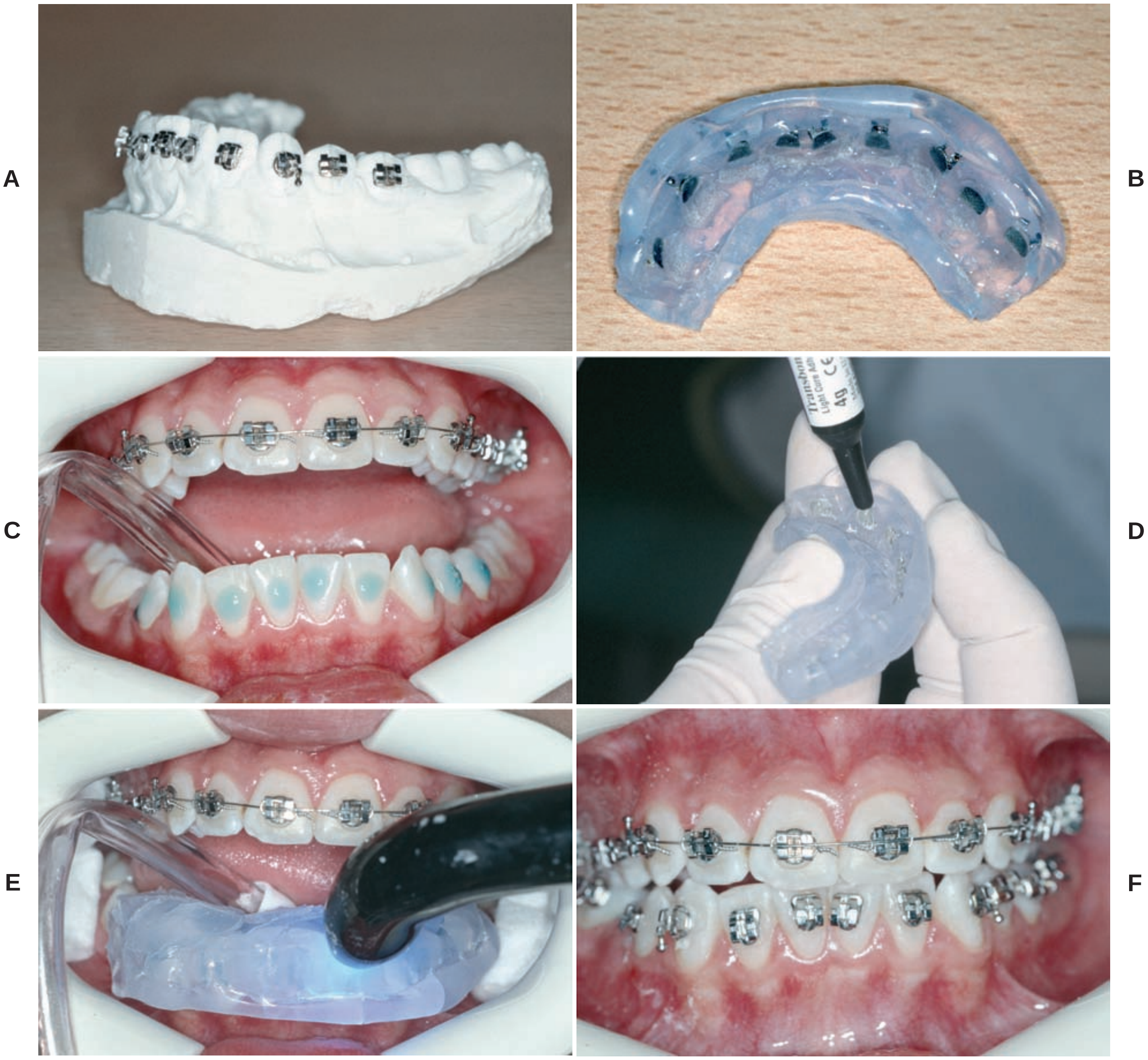

FIGURE 21-15 Indirect bonding using a clear tray (Memosil, Heraeus Kulzer, Armonk, NY) and a light cure adhesive.

setting is obtained more easily with direct bonding. However, when correct technique is used, failure rates with direct and indirect bonding fall within a clinically acceptable range. At present, the individual practitioner may use either method based on practice routine, auxiliary personnel, and clinical ability and experience. For instance, indirect bonding is more likely to be used when all brackets are placed at one time at the start of treatment than with a progressive strap-up. In lingual orthodontics, the indirect technique also is a prerequisite for good bracket alignment because direct visualization has evident difficulties.

Although bracket placement in the laboratory may suggest more accurate positioning, this has not been confirmed in studies comparing direct and indirect bonding. More recent computer-assisted measuring devices for indirect bonding may improve the accuracy of bracket placement and take into account anatomic variations, overcorrections, and mechanical deficiencies of preadjusted appliances.[38,39]

Several products have been introduced that are specifically designed for indirect bonding procedures. Different types of custom base composites may be light cured, chemically cured, or thermally cured.[35,37] One system (from Reliance Orthodontics) recommends the use of thermally cured base composite (Therma-Cure), Enhance adhesion booster, and a chemically cured sealant (Custom I.Q.). Another system (from 3M/Unitek) recommends the use of light-cured base composite (Transbond XT) and chemically cured sealant (Sondhi Rapid Set) in the clinic (Figure 21-16). Studies comparing the in vitro bond strengths obtained with these two indirect

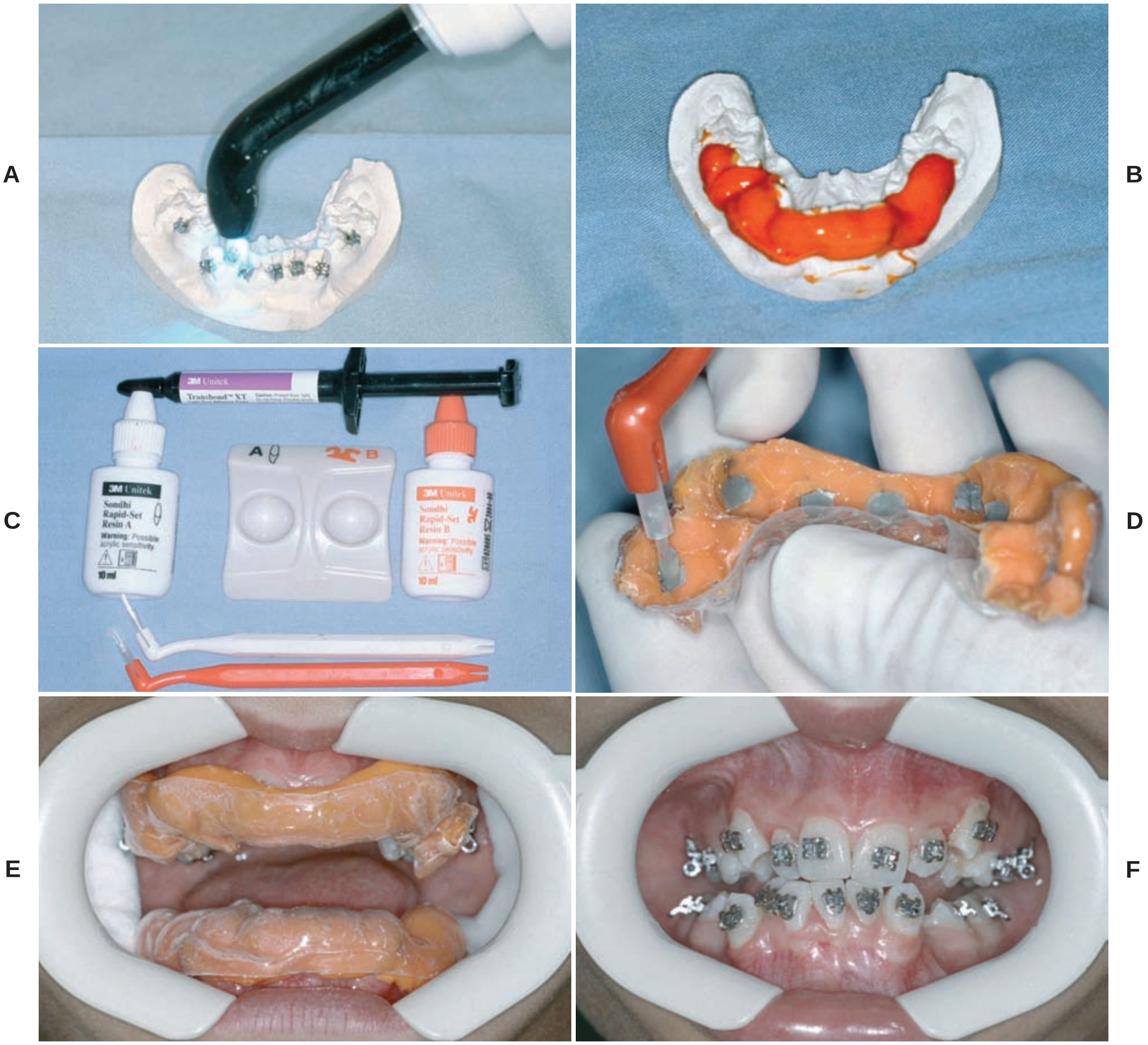

FIGURE 21-16 Indirect bonding using light-cured base composite (Transbond XT) and chemically cured sealant (Sondhi Rapid Set). See text for details.

systems compared with direct bonding with light-cured composite resin (Transbond XT) indicate that the differences between the indirect and direct methods are small and probably of little clinical significance. Using single bracket trays for transfer, Klocke et al.[35] found that indirect bonding with Sondhi Rapid Set showed bond strength similar to direct bonding with Transbond XT, whereas indirect bonding with Custom I.Q. showed lower bond strengths. However, Polat et al.,[37] using full-arch transfer trays of putty silicone material, found higher bond strength when they used thermally cured bracket bases indirectly bonded with Custom I.Q. than with light-cured bases (Transbond XT) bonded with Sondhi Rapid Set. In a clinical test for 9 months in 15 patients whose teeth were indirectly bonded with either of the two techniques (thermally cured bases bonded with Custom I.Q. or light-cured bases bonded with Sondhi Rapid Set) using a split-mouth design, no significant differences in bond failure rates were found.

Clinical Procedure. As mentioned, several indirect bonding techniques have proved reliable in clinical practice (see Figures 21-15 and 21-16). The techniques differ in the way the brackets are attached temporarily to the model, the type of transfer tray used (e.g., full-arch, sectioned full-arch, single tooth, and double-tray system), the sealant or resin used, whether segmented or full bonding is used, and the way the transfer tray is removed so as not to exert excessive force on a still-maturing bond.

Indirect Bonding with Composite Custom Bracket Base. Most current techniques use composite resin custom bracket bases (light cured, thermally cured, or chemically cured) and a chemically cured sealant as the

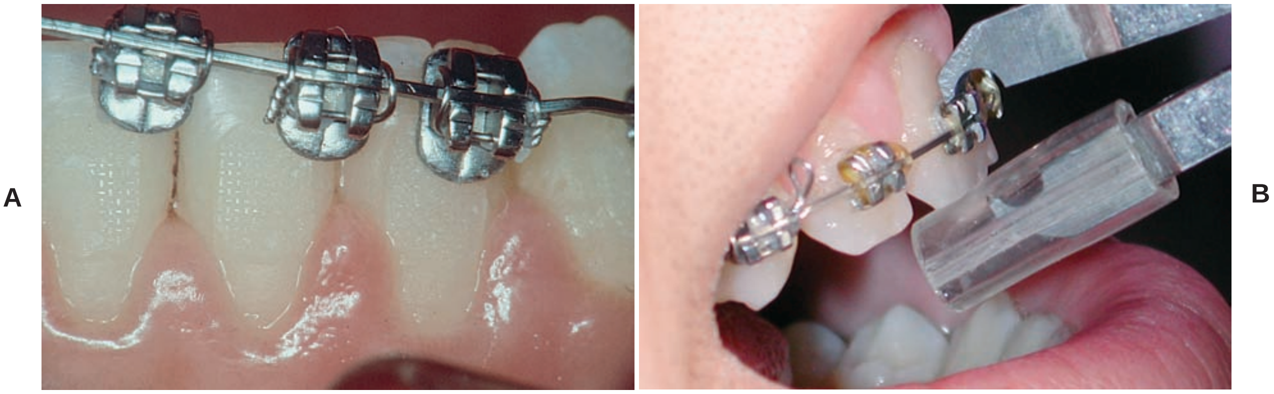

FIGURE 21-17 Bracket removal with pliers. Still ligated in place, the brackets are gripped one by one with 095 Orthopli bracket-removing pliers and lifted outwardly at a 45-degree angle. The indentation in the pliers fits into the gingival tie-wings for a secure grip. This is a quick and gentle technique that leaves the brackets intact and fit for recycling, if so desired. **A,** The bond breaks in the adhesive–bracket interface, and the pattern of the mesh-backing is visible on the adhesive remaining on the teeth. **B,** Same technique for maxillary steel brackets.

clinical bonding resin. The following procedure may be useful (see Figure 21-16):

1. Take an impression and pour up a stone (not plaster) model.
2. Select brackets for each tooth.
3. Isolate the stone model with a separating medium.
4. Attach the brackets to the teeth on the model with light-cured or thermally cured composite resin, or use adhesive precoated brackets.
5. Check all measurements and alignments. Reposition if needed.
6. Make a transfer tray for the brackets. Material can be putty silicone, thermoplastics, or similar.
7. After removing the transfer trays, gently sandblast the adhesive bases with a microetching unit, taking care not to abrade the resin base.[40]
8. Apply acetone to the bases to dissolve the remaining separating medium.
9. Prepare the patient's teeth as for a direct application.
10. Apply Sondhi Rapid Set resin A to the tooth surfaces and resin B to the bracket bases. (If Custom I.Q. is used, apply resin B to the teeth and resin A to the bases).
11. Seat the tray on the prepared arch and with the fingers apply equal pressure to the occlusal, labial, and buccal surfaces. Hold for a minimum of 30 seconds, and allow for 2 minutes or more of curing time before removing the tray.
12. Remove excess flash of resin from the gingival and contact areas of the teeth with a scaler or contra-angle handpiece and tungsten carbide bur.

Rebonding

Bonded brackets that become loose during treatment consume much chair time are poor publicity for the office and are a nuisance to the orthodontist. The best way to avoid loose brackets is to adhere strictly to the rules for good bonding mentioned previously. Use of a quick technique for rebonding loose brackets also is important.

A loose metal bracket is removed from the archwire. Any adhesive remaining on the tooth surface is removed with a tungsten carbide bur. The adhesive remaining on the loose bracket is treated by sandblasting (Figure 21-7) until all visible bonding material is removed from the base. The tooth then is etched with Ultraetch 35% phosphoric acid gel for 15 seconds. On inspection the enamel surface may not be uniformly frosty because some areas still may retain resin. The phosphoric acid will re-etch any exposed enamel and remove the pellicle on any exposed resin. After priming, the bracket is rebonded. The neighboring brackets are religated first, and then the rebonded bracket is ligated. The bond strength for sandblasted rebonded brackets is comparable to the success rate for new brackets.

A loose ceramic bracket should be replaced with a new, intact bracket for optimum bond strength.

Recycling

Several methods of recycling debonded attachments for repeat use, by commercial companies or by a duplicated procedure in office, are available. The main goal of the recycling process is to remove the adhesive from the bracket completely without damaging or weakening the delicate bracket backing or distorting the dimensions of the bracket slot. Recycling of brackets has dropped off considerably over the past years and now is done by less than 10% of orthodontists in the United States.[1]

Conclusion

Bonding of brackets has changed the practice of orthodontics and has become a routine clinical procedure in a remarkably short time.[1] Modifications of technical devices, sealants and adhesives, attachments, and procedures are continuing. Careful study of the available information by the orthodontist will be mandatory in keeping up with progress. However, cautious interpretation of in vitro studies is recommended because the in vivo results do not always reflect and verify the laboratory findings. Long-term follow-up studies are needed in several areas.

At present, the authors are using bonded brackets routinely on all teeth except maxillary first molars. In most routine situations, banding maxillary first molars provides a stronger attachment and availability of lingual sheaths (such as for transpalatal bars, elastics, and headgear) and may give some interproximal caries protection. Finally, the procedure described for bonding mandibular second and third molars has proved to be successful in clinical use over many years. This is particularly true in adolescents, whose teeth are erupting during the course of treatment. The mandibular second molar is better suited for bonding than for banding because gingival emergence of the buccal surface precedes emergence of the distal surface.

DEBONDING

The objectives of debonding are to remove the attachment and all the adhesive resin from the tooth and restore the surface as closely as possible to its pretreatment condition without inducing iatrogenic damage. To obtain these objectives, a correct technique is of fundamental importance. Debonding may be unnecessarily time consuming and damaging to the enamel if performed with improper technique or carelessly.

Because several aspects of debonding are controversial, debonding is discussed in detail as follows:

- Clinical procedure
- Characteristics of normal enamel
- Influence of different debonding instruments on surface enamel
- Amount of enamel lost in debonding
- Enamel tearouts
- Enamel cracks (fracture lines)
- Adhesive remnant wear
- Reversal of decalcifications

Clinical Procedure

Although several methods have been recommended in the literature for bracket removal and adhesive cleanup, and some discrepancy of opinion still exists, the techniques described have proved successful in the authors' experience. Their rationales are mentioned throughout the ensuing discussion.

The clinical debonding procedure may be divided into two stages:

1. Bracket removal
2. Removal of residual adhesive

Bracket Removal: Steel Brackets. Several different procedures for debracketing with pliers are available. An original method was to place the tips of a twin-beaked pliers against the mesial and distal edges of the bonding base and cut the brackets off between the tooth and the base. Several pliers are available for this purpose. A gentler technique is to squeeze the bracket wings mesiodistally and lift the bracket off with a peel force. This is particularly useful on brittle, mobile, or endodontically treated teeth.

The brackets are deformed easily and are less suitable for recycling when the latter method is used. The recommended technique, in which brackets are not deformed, is illustrated in Figure 21-17. This technique uses a peeling-type force, which is most effective in breaking the adhesive bond. A peel force, as in peeling an orange, creates peripheral stress concentrations that cause bonded metal brackets to fail at low force values. The break is likely to occur in the adhesive–bracket interface, thus leaving adhesive remnants on the enamel. Attempts to remove the bracket by shearing it off (as is done in removing bands) can be traumatic to the patient and potentially damaging to the enamel.

Bracket Removal: Ceramic Brackets. With the introduction of ceramic brackets, a new concern over enamel fracture and loss from debonding has arisen. Because of differences in bracket chemistry and bonding mechanisms, various ceramic brackets behave differently on debonding. For example, ceramic brackets using mechanical retention cause fewer problems in debonding than do those using chemical retention. More recent ceramic brackets have a mechanical lock base and a vertical slot that will split the bracket by squeezing. Separation is at the bracket–adhesive interface, with little risk of enamel fracture. In this regard, some knowledge about the normal frequency, distribution, and orientation of enamel cracks in young and in older teeth is important (see Enamel Cracks).

Ceramic brackets will not flex when squeezed with debonding pliers. Cutting the brackets off with gradual pressure from the tips of twin-beaked pliers oriented mesiodistally close to the bracket–adhesive interface is not recommended because it might introduce horizontal enamel cracks.

Low-speed grinding of ceramic brackets with no water coolant may cause permanent damage or necrosis of dental pulps. Therefore, water cooling of the grinding sites is necessary. Thermal debonding and the use of lasers have the potential to be less traumatic and less risky for enamel damage, but these techniques are still at an introductory stage.

Removal of Residual Adhesive. Because of the color similarity between present adhesives and enamel, complete removal of all remaining adhesive is not achieved

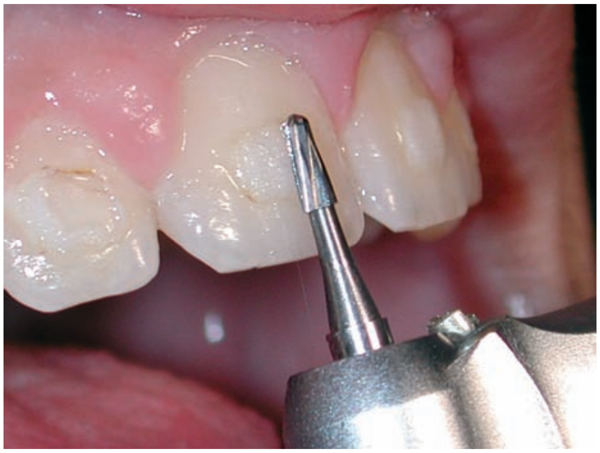

FIGURE 21-18 Adhesive remaining after debracketing may be removed with a tungsten carbide bur at about 30,000 rpm.

easily. Many patients may be left with incomplete resin removal, which is not acceptable. Abrasive wear of present bonding resins is limited, and remnants are likely to become unaesthetically discolored with time.

The removal of excess adhesive may be accomplished by (1) scraping with a sharp band or bond-removing pliers or with a scaler[4] or by (2) using a suitable bur and contra-angle (Figure 21-18). Although the first method is fast and frequently successful on curved teeth (premolars, canines), it is less useful on flat anterior teeth. A risk also exists of creating significant scratch marks.

The preferred alternative is to use a suitable dome-tapered tungsten carbide bur (No. 1171 or No. 1172) in a contra-angle handpiece (see Figure 21-18). Clinical experience and laboratory studies[41] indicate that about 30,000 rpm is optimal for rapid adhesive removal without enamel damage. Light painting movements of the bur should be used so as not to scratch the enamel. Water cooling should not be used when the last remnants are removed because water lessens the contrast with enamel. Speeds higher than 30,000 rpm using fine fluted tungsten carbide burs may be useful for bulk removal but are not indicated closer to the enamel because of the risk of marring the surface. Even ultrafine high-speed diamonds produce considerable surface scratches. Slower speeds (10,000 rpm and less) are ineffective, and the increased jiggling vibration of the bur may be uncomfortable to the patient.

When all adhesive has been removed, the tooth surface may be polished with pumice (or a commercial prophylaxis paste) in a routine manner. However, in view of the normal wear of enamel, this step may be optional.

CHARACTERISTICS OF NORMAL ENAMEL

Apparently not every clinician is familiar with the dynamic changes that continuously take place throughout life in the outer, most superficial enamel layers.[5] Because a tooth surface is not in a static state, the normal structure differs considerably among young, adolescent, and adult teeth.[5] Normal wear must be considered in any discussion of tooth surface appearance after debonding. The characteristics are visible on the clinical and microscopic levels.

The most evident clinical characteristics of young teeth that have just erupted into the oral cavity are the perikymata that run around the tooth over its entire surface (Figure 21-19). By scanning electron microscopy the open enamel prism ends are recognized as small holes. In adult teeth the clinical picture reflects wear and exposure to varying mechanical forces (e.g., toothbrushing habits and abrasive foodstuffs). In other words, the perikymata ridges are worn away and replaced by a scratched pattern (Figure 21-20). Frequently, cracks are visible. Scanning electron microscopy shows no evidence of prism ends or perikymata; instead deep and finer scratches run across the surface (see Figure 21-20). Teeth in adolescents reflect an intermediate stage (Figure 21-21, *B*). According to Mannerberg,[5] at 8 years of age practically all teeth show evident perikymata on one third to two thirds of the tooth surface; at age 13, the number is reduced to 70% to 80%; and at age 18, only 25% to 50% of teeth demonstrate such ridges. Using a replica technique to study the gradual removal of artificial scratch marks on the teeth, Mannerberg found the normal wear to range from 0 to 2 mm per year. For comparison, a sandpaper disk that touches the enamel only a fraction of a second will leave scratch marks at least 5 mm deep.

Influence on Enamel by Different Debonding Instruments

By proposing an enamel surface index with five scores (0 to 4) for tooth appearance and using replica scanning electron microscopy and step-by-step polishing, Zachrisson and Årtun[41] were able to compare different instruments commonly used in debonding procedures and rank their degrees of surface marring on young permanent teeth.

The study demonstrated that (1) diamond instruments were unacceptable (score 4), and even fine diamond burs produced coarse scratches and gave a deeply marred appearance; (2) medium sandpaper disks and a green rubber wheel produced similar scratches (score 3) (Figure 21-22) that could not be polished away; (3) fine sandpaper disks produced several considerable and some even deeper scratches and an appearance largely resembling that of adult teeth (score 2); (4) plain cut and spiral fluted tungsten carbide burs operated at about 25,000 rpm were the only instruments that provided the satisfactory surface appearance (score 1); however, (5) none of the instruments tested left the virgin tooth surface with its perikymata intact (score 0).

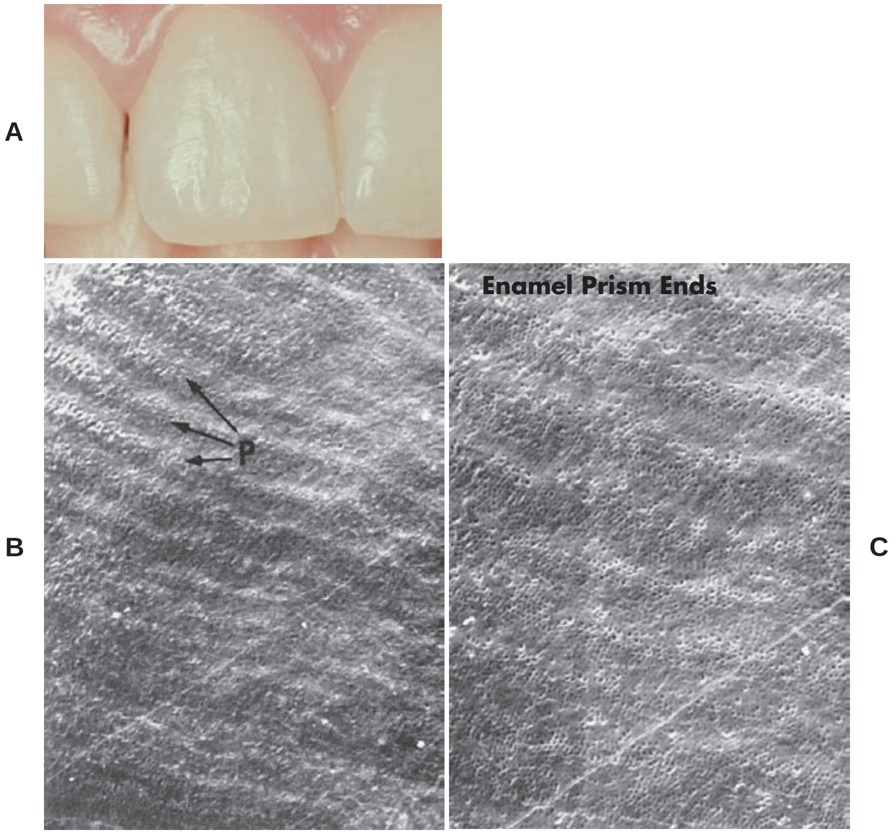

Figure 21-19 **A,** Typical perikymata in a 10-year-old boy. **B,** Scanning electron microscopy appearance (×50.) **C,** Enlargement of the central portion in **B,** showing numerous small pits (the typical signs of enamel prism ends) and a crack. *P,* Perikymata.

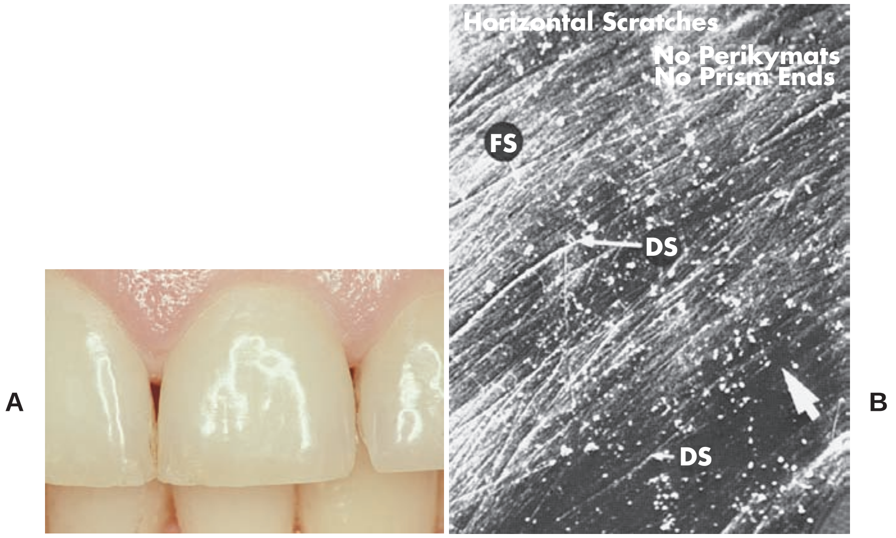

FIGURE 21-20 **A,** In adult teeth the perikymata remain in developmental grooves. Note the other irregularities: vertical and horizontal scratches, pits, internal white spots, vertical cracks **(B)** (scanning electron micrograph, ×50). Neither perikymata nor prism end openings are visible. However, note the severe horizontal scratches. Most are fine (*FS*), but some are coarser and deeper (*DS*).

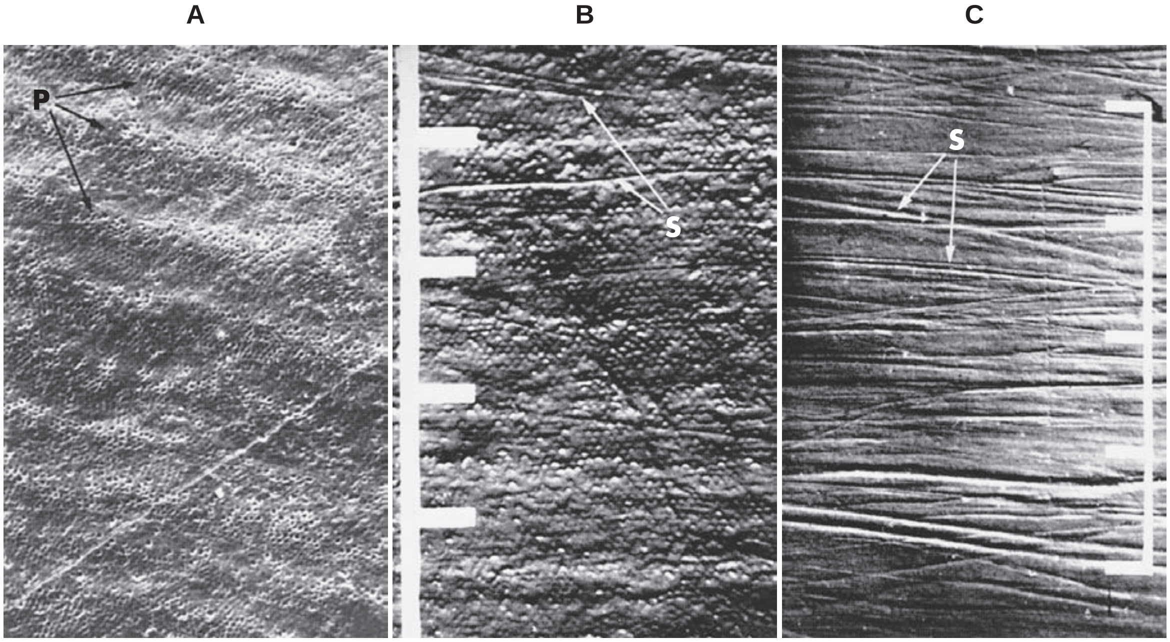

FIGURE 21-21 Scanning electron micrographs of normal enamel in young **(A),** adolescent **(B),** and adult **(C)** teeth. Note the gradual transition from virgin tooth with perikymata (*P*) and open prism ends to a gradually increasing scratched (S) appearance. (Scale division is 0.1 mm.) (**B, C,** Courtesy F. Mannerberg, Malmö, Sweden.)

The clinical implication of the study is that tungsten carbide burs produced the finest scratch pattern with the least enamel loss and are superior in their ability to reach difficult areas (Figure 21-23).

Amount of Enamel Lost in Debonding

The orthodontic literature discusses how much enamel actually is removed in routine bonding and debonding. The amount is related to several factors, including the instruments used for prophylaxis and debonding and the type of adhesive resin used.

An initial prophylaxis with bristle brush for 10 to 15 seconds per tooth (which is in fact much longer than that used in clinical routines) may abrade away as much as 10 microns of enamel, whereas only about 5 microns may be lost when a rubber cup is used.

Cleanup of unfilled resins may be accomplished with hand instrumentation only, and this procedure generally results in a loss of 5 to 8 microns of enamel. Depending on the instruments used for prophylaxis, total enamel loss for unfilled resins may be 2 to 40 microns.

Adequate removal of filled resin generally requires rotary instrumentation; the enamel loss then may be 10 to 25 microns.

In a clinical perspective, the enamel loss encountered with routine bonding and debonding procedures, exclusive of deep enamel fractures or gouges resulting from injudicious use of hand instrument or burs, is not significant in terms of total thickness of enamel. The surfaces usually bonded have a thickness of 1500 to 2000 microns. The claim that removal of the outermost layer of enamel (which is particularly caries resistant and fluoride rich) may be harmful also is not in accordance with recent views on tooth surface dynamics and with clinical experience over many years. The facial tooth surfaces are left smooth and self-cleansing after debonding. Caries have been demonstrated not to develop in such sites even if the entire enamel layer is removed.

Enamel Tearouts

Localized enamel tearouts have been reported to occur associated with bonding and debonding metal and ceramic brackets. Tearouts may be related at least in part to the type of filler particles in the adhesive resin used for bonding and to the location of bond breakage.

Possibly small filler particles may penetrate into the etched enamel to a greater degree than macrofillers may penetrate. For instance, the holes corresponding to the dissolved enamel prism cores in the central etch type (see Figure 21-1) are 3 to 5 microns in diameter. On debonding the small fillers may reinforce the adhesive tags. The macrofillers, however, create a more natural break point in the enamel–adhesive interface. Similarly, with unfilled resins there is no natural break point.

Ceramic brackets using chemical retention cause enamel damage more often than those using mechanical retention. This damage occurs probably because the location of the bond breakage is at the enamel–adhesive interface rather than at the adhesive–bracket interface.

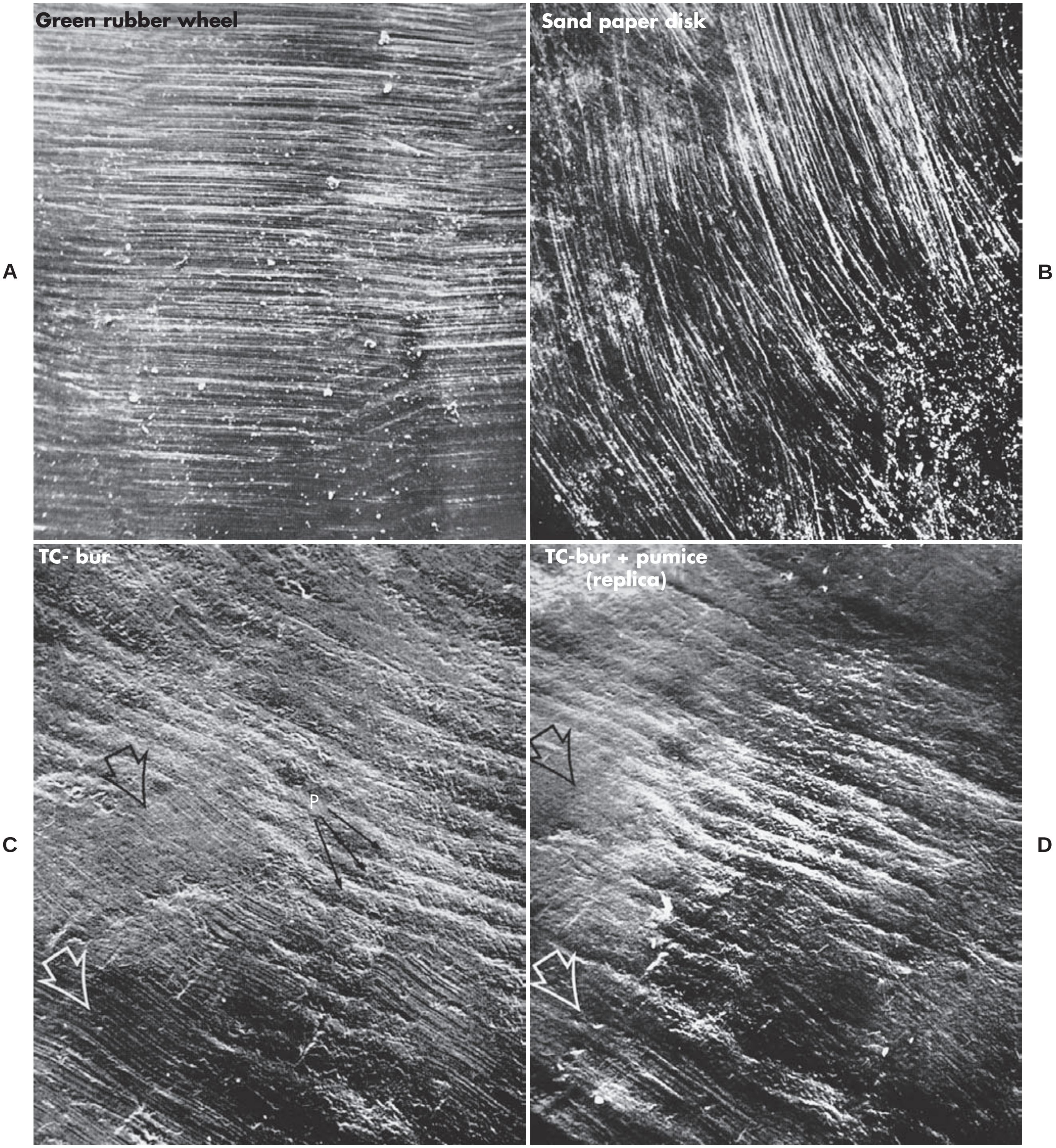

FIGURE 21-22 Comparison of the effect of three debonding techniques on the enamel surface. **A–C,** Scanning electron micrographs after adhesive removal without subsequent polishing (×50). Note that the scratches are of similar appearance in **A** and **B** but that in **C** only slight faceting with fine scratches (*open arrows*) is intermingled with the perikyma ridges (*P*). **D,** Same area as in **C** in replica after pumicing. The surface is smoother (*arrows*).

The clinical implications are (1) to use brackets that have mechanical retention and debonding instruments and techniques that primarily leave all or the majority of composite on the tooth (see Figure 21-17, *A*) and (2) to avoid scraping away adhesive remnants with hand instruments.

Enamel Cracks (Fracture Lines)

Cracks, occurring as split lines in the enamel, are common but often are overlooked at clinical examination because most are difficult to distinguish clearly without special technique; generally they do not show up on routine,

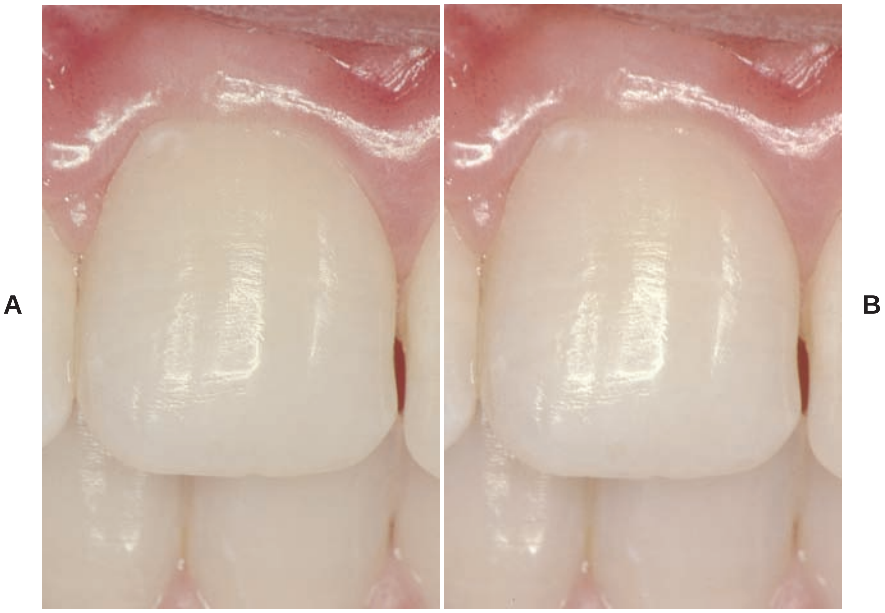

FIGURE 21-23 **A,** After debonding with a tungsten carbide bur at low speed. Gentleness of technique is reflected by the evident perikymata-like pattern on debonded teeth **(B).**

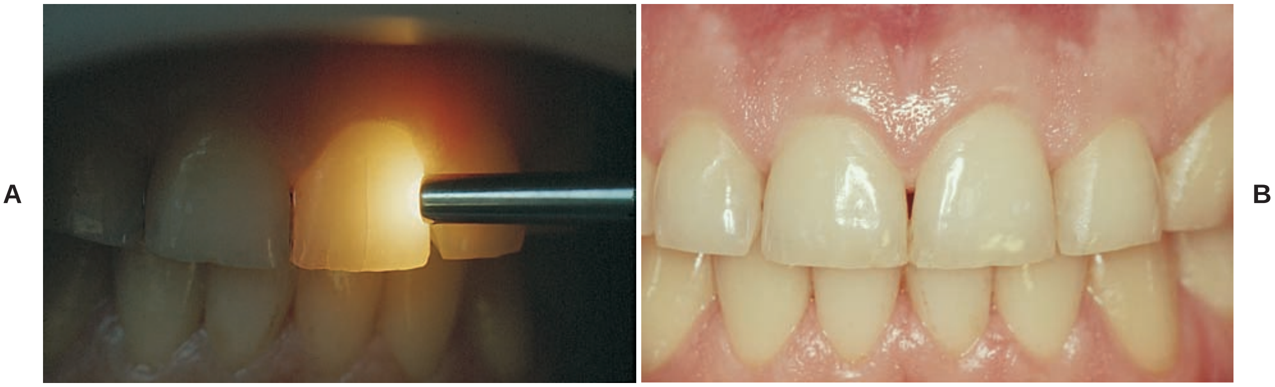

FIGURE 21-24 Enamel cracks generally are not visible on intraoral photographs. Several cracks clearly seen on the left central incisor with fiberoptic transillumination **(A)** are undetectable by routine photography **(B).** Note the vertical orientation of the cracks.

intraoral photographs (Figure 21-24). Thus, finger shadowing in good light or, preferably, fiberoptic transillumination is needed for a proper impression of the crack (Figure 21-24). The origin of cracks is multicausal. Different forms of mechanical and thermal insult may fracture the enamel cap after eruption; this results from the significant difference in rigidity between enamel and dentin.

A distinct possibility is that the sharp sound sometimes heard on removal of bonded orthodontic brackets with pliers is associated with the creation of enamel cracks. The occurrence of cracks in debonded, debanded, and orthodontically untreated teeth was discussed in a study by Zachrisson et al.[42] Using fiberoptic light technique, the researchers examined more than 3000 teeth in 135 adolescents. The prevalence of cracks, their distribution per tooth, their location on the tooth surface, and the type (pronounced versus mild, horizontal versus vertical) were described. The most important findings were that (1) vertical cracks are common (in fact, more than 50% of all teeth studied had such cracks), but individual variation is great; (2) few horizontal and oblique cracks are observed normally; (3) no significant difference existed between the three groups regarding prevalence and location of cracks; and (4) the most notable cracks (i.e., those invisible under normal office illumination) are on the maxillary central incisors and canines.

The clinical implication of these findings is that if an orthodontist (1) observes several distinct enamel cracks on the patient's teeth after debonding, particularly on teeth other than maxillary canines and central incisors or (2) detects cracks in a predominantly horizontal direction, this is an indication that the bonding or debonding technique used may need improvement. With ceramic brackets, the risk for creating enamel cracks is greater than for metal brackets. The lack of ductility may generate stress in the adhesive–enamel interface that may produce enamel cracks at debonding.

Another clinical implication may be the need for pretreatment examination of cracks, notifying the patient and the parents if pronounced cracks are present. The reason for this examination is that patients may be overly inspective after appliance removal and may detect cracks that were present before treatment of which they were unaware. They may question the orthodontist about the cause of the cracks. Without pretreatment diagnosis and documentation (most cracks are not visible on routine intraoral slides), proving that such cracks are indeed unrelated to the orthodontic treatment is almost impossible.

Adhesive Remnant Wear

Frequently, adhesive has been found on the tooth surface, even after attempts to remove it with mechanical instruments. Because of color resemblance to the teeth, particularly when wet, residual adhesive easily may remain undetected. In other instances, adhesive may be left on purpose because the operator expects that it will wear off with time.

Abrasive wear depends on the size, type, and amount of reinforcing fillers in the adhesive. When at the time of debonding, varying amounts of adhesive purposely were left on the teeth assumed to be the most exposed to toothbrushing forces (i.e., the maxillary left canine and one neighboring tooth), the abrasion over a 12-month period was almost insignificant in clinical terms.[43] Only thin films of residual adhesive showed any reduction in size.

In the light of these findings, it seems too optimistic to believe that residual filled adhesive will disappear quickly by itself after debonding; it appears irresponsible to leave large accumulations of adhesive.

Reversal of Decalcification

White spots or areas of demineralization are carious lesions of varying extent. The incidence and severity of white spots after a full term of orthodontic treatment have been studied by several authors. The general conclusion was that individual teeth, banded or bonded, may exhibit significantly more white spot formation than may untreated control teeth (Figure 21-25). This degree of iatrogenic damage suggests the need for preventive programs using fluoride associated with fixed appliance orthodontic treatment.

Daily rinsing with dilute (0.05%) sodium fluoride solution throughout the periods of treatment and retention, plus regular use of a fluoride dentifrice, is recommended as a routine procedure for all orthodontic patients. The weak fluoride mouth rinse is effective yet has few risks, and most patients can manage to use it easily for 1 to 2 years. Definite responsibility also must be given to the patient to avoid decalcifications during treatment. In addition, painting a fluoride varnish or new effective anticaries agents over caries-susceptible sites at each visit may be useful in patients with hygiene problems.

Much evidence now exists from in vivo and in vitro studies to support the claim that small carious lesions can heal, a process usually referred to as remineralization. Dental caries may be the result of a dynamic series of events, with remineralization occurring naturally during the formation of a carious lesion. Fluoride ions greatly enhance the degree of remineralization (incorporation of calcium and phosphate from the saliva) and reduce the time required for this mechanism to occur. Only lower levels of fluoride are required to trigger the mechanism; raising the fluoride level further does not result in a greater degree of remineralization. Fluoride ions may be concentrated into demineralized areas, which thereby act as reservoirs promoting remineralization from the saliva.

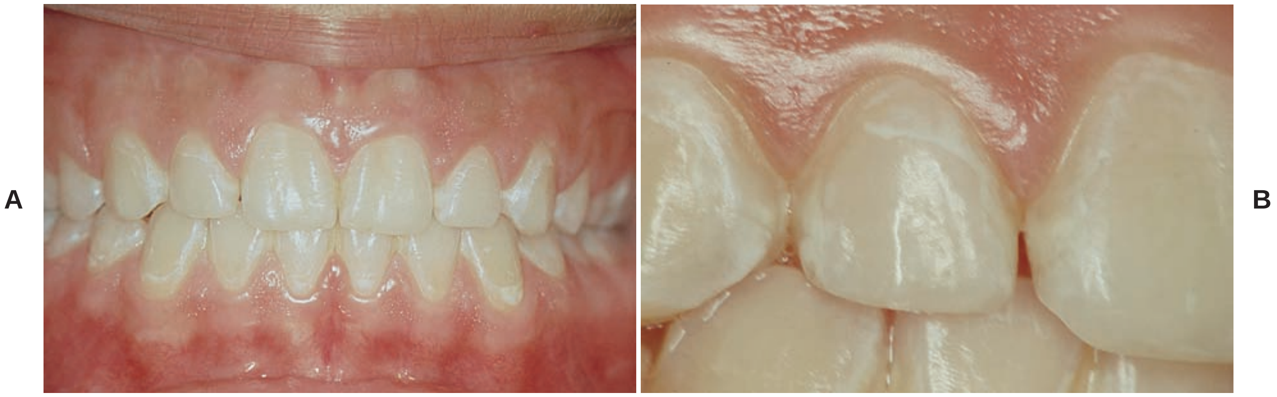

FIGURE 21-25 Extreme degree of enamel demineralization after orthodontic treatment in a caries-prone patient **(A).** Note that white spot lesions can occur on multiple teeth. **B,** The contour of the bonded brackets is visible on several teeth.

Removal of the cariogenic challenge after debonding results in arrest of further demineralization, and a gradual regression of the lesion at the clinical level takes place primarily because of surface abrasion with some redeposition of minerals. Visible white spots that develop during orthodontic therapy should not be treated with concentrated fluoride agents immediately after debonding because this procedure will arrest the lesions and prevent complete repair. In the future, orthodontists can expect more effective methods for caries reversal to become available.

At present it seems advisable to recommend a period of 2 to 3 months of good oral hygiene but without fluoride supplementation associated with the debonding session. This procedure should reduce the clinical visibility of the white spots. More fluoride may tend to precipitate calcium phosphate onto the enamel surface and block the surface pores, which limits remineralization to the superficial part of the lesion, and the optical appearance of the white spot is not reduced.

Microabrasion

When the remineralizing capacity of the oral fluids is exhausted and white spots are established (Figure 21-26; see also Figure 21-25), microabrasion is the optimal way to remove superficial enamel opacities. By the use of this technique, one can eliminate enamel stains with minimal enamel loss.

Clinical procedure: A custom-made abrasive gel is prepared with 18% hydrochloric acid, fine powdered pumice, and glycerin. The active mixture is applied as follows[44]:

1. The gingiva is isolated using blockout resin or rubber dam. Dental floss may be useful to prevent soft tissue contact and injury from the acid.
2. The abrasive gel is applied using an electric toothbrush for 3 to 5 minutes. The original toothbrush tip is modified by cutting the peripheral bristles to create a smaller brush tip to fit on tooth surfaces better.
3. Rinse for 1 minute.

To prevent enamel pitting, the acid should not be left on the tooth for an extended time. For best results, and depending on the severity of the lesions, the procedure can be repeated monthly 2 to 3 times. This makes stains disappear gradually.

The microabrasion technique is effective in removing white spots and streaks and brown-yellow enamel discolorations. In cases of more extensive mineral loss, however, grinding with diamond burs under water cooling or composite restorations are inevitable.

BONDED RETAINERS

Permanent maintenance of the achieved result after successful treatment of malocclusion is undoubtedly a great, if not the greatest, problem for orthodontic clinicians. This is especially true for adult patients. Therefore the relative scarcity of literature on the subject is surprising.

The use of fixed lingual bonded retainers is increasing,[1] and the various forms allow more differentiated retention than before. Bonded retainers also have other advantages:

1. Completely invisible from the front
2. Reduced need for long-term patient cooperation
3. Long-term (up to 10 years) and even permanent retention while conventional retainers do not provide the same degree of stability

The term *differential retention*, as introduced by the late Dr. James L. Jensen, implies that special attention is directed toward the strongest or most important predilection site for relapse in each case. Thus the most appropriate mode of retention for the postorthodontic situation in question should be used and should be based on a careful evaluation of the pretreatment diagnostic records, habits, patient cooperation, growth pattern, and age. Implicit in the introduction of the acid-etch technique for direct-bonded retainers is the provision of a variety of new methods for retention. This discussion reviews

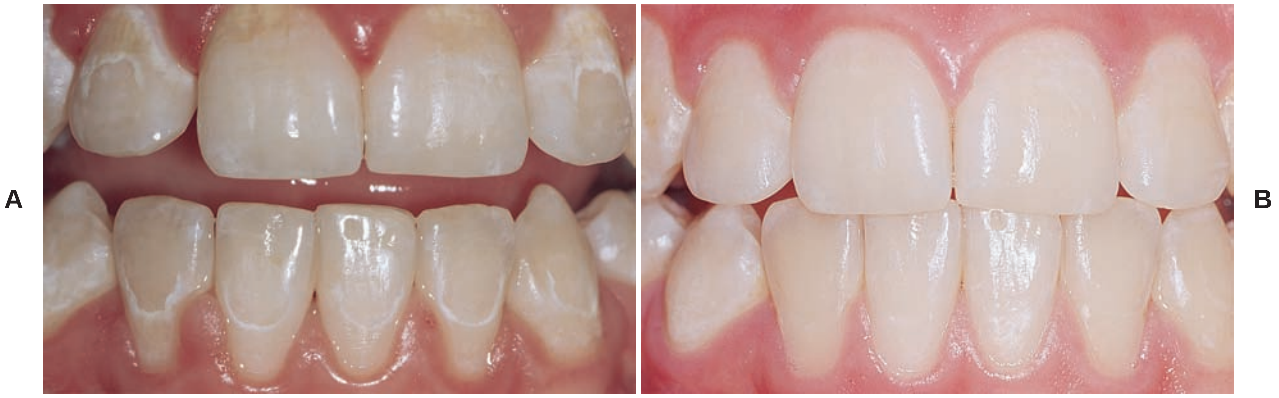

FIGURE 21-26 White spot lesions before **(A),** and after **(B)** microabrasion. See text for details.

the current level of technical expertise regarding bonded retainers.

Because the technique is comparatively new, any discussion of it is weakened by the evident lack of published clinical and long-term research findings with various types of retainers and splints.[45] For this reason, the discussion in a large part is based on the authors' own experiences. The following subdivisions are used:

- Mandibular canine-to-canine (3-3) retainer bar
- Direct contact splinting
- Flexible spiral wire retainers
- Hold retainers for individual teeth

In the following pages, two different types of retainer wire are discussed—a thick one (0.030 or 0.032 inch) and a thin one (0.0215 inch)—with entirely different indications and modes of bonding.

Bonded Lingual Canine-to-Canine Retainer Bar

Lingually bonded 3-3 retainers can provide excellent results[45–47,49,50] (Figure 21-27) if meticulous construction and bonding techniques are followed, along with some modifications of the original design.

In differential retention philosophy the purpose of a bonded 3-3 retainer bar is (1) to prevent incisor recrowding, (2) to hold the achieved lower incisor position in space, and (3) to keep the rotation center in the incisor area when a mandibular anterior growth rotation tendency is present. The retainer bar may be indicated, particularly in persons with a flat functional occlusal plane, open bite, Class II with rotation center in the premolar area (Björk's anterior rotation Type III), or Class III growth tendency.

The standard appliance is bonded to the lingual surfaces of the canine teeth. The bar, which originally was constructed from plain blue Elgiloy wire with a loop at each terminal end for added retention[45] (see Figure 21-27, *A*) was replaced by a similar-diameter multistrand wire (see Figure 21-27, *B*). For some patients, this wire proved not solid enough and distorted, and the wire was difficult to bend to optimal fit. These drawbacks are eliminated in the third-generation design (see Figure 21-27, *C, D*), in which the bar is made from round 0.032-inch stainless steel or 0.030-inch gold-coated wire,[46] sandblasted on the ends for improved micromechanical retention. Bonding is done with a chemically or light-cured composite resin because such adhesives provide the strongest bonds and show comparatively little abrasion over extended periods.[43]

In selected cases when the lower first premolars at the start of treatment are blocked out labially, severely rotated, or tipped, extension of the 3-3 bar to include also the first premolars (43-34 retainer) is useful. This is

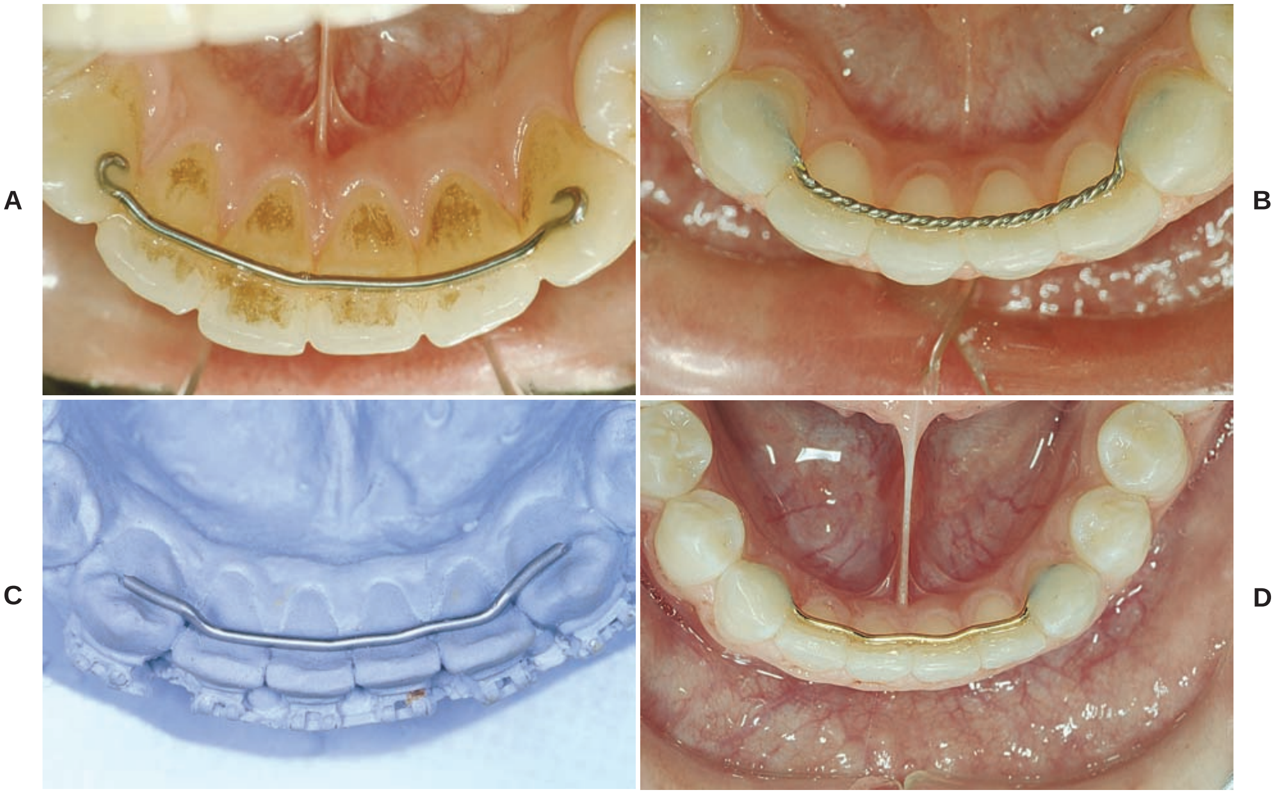

FIGURE 21-27 **A,** First-generation bonded mandibular lingual 3-3 retainer. **B,** Second-generation 3-3 retainer. **C, D,** Third-generation 3-3 retainer in stainless steel and gold-coated bar, respectively.

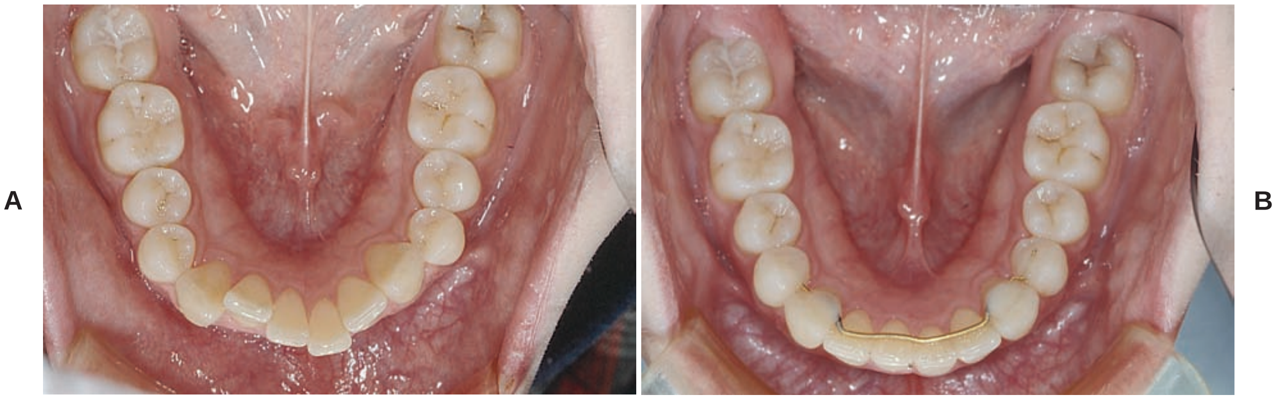

FIGURE 21-28 **A,** A 43-34 retainer can be used when the first premolars are blocked out labially or tipped mesially pretreatment. **B,** The 0.030-inch 3-3 retainer bar is extended by means of a thin (0.0215-inch coaxial) gold-coated wire between the canine and first premolar.

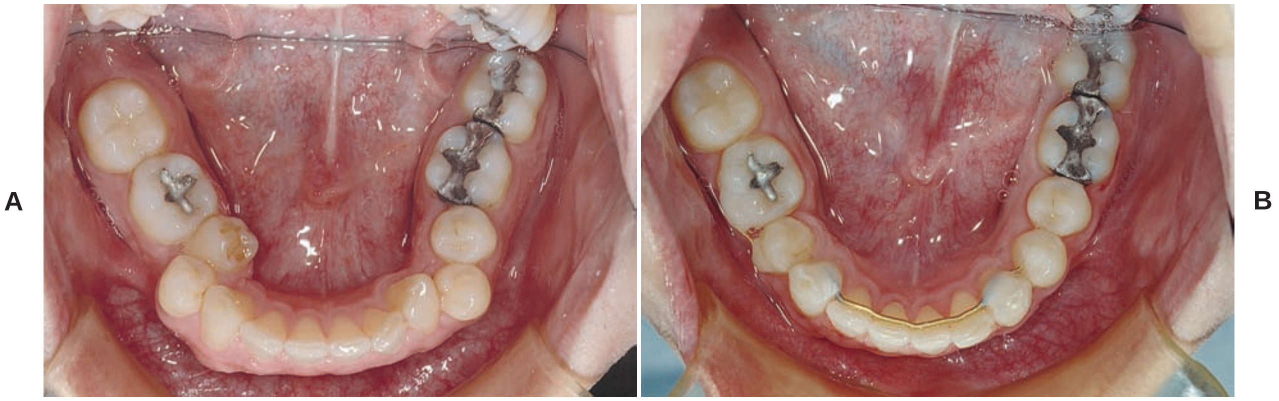

FIGURE 21-29 **A,** Adult patient with pretreatment blocked-out right second and left first premolar treated with extraction of the second premolar on the right side. **B,** Final result is retained by means of a short labial gold-coated retainer in the closed extraction site and a 3-34 retainer.

done simply by adding and bonding a small piece of thin wire between the premolar and canine (Figures 21-28 and 21-29). The 43-34 design also may be used when after orthodontic leveling of the six anterior mandibular teeth the orthodontist desires to prevent their reerupting above the functional occlusal plane.

Some companies supply preformed lingual 3-3 retainers with bonding pads. These may be more difficult to fit and bond tightly. At the same time, obtaining maximal contact on the lingual surfaces of all four incisors also may be more difficult.

Failure Analysis. Initial failures with first-generation bonded lingual 3-3 retainers were classified into two types.[47] Type I failure was related to separation at the tooth–adhesive interface and occurred with the highest frequency. Type I failure most commonly resulted from moisture contamination or movement of the lingual bar during the initial polymerization of the composite. Type II failure occurred at the adhesive–retainer wire interface and resulted from inadequate bulk of adhesive for sufficient strength (or abrasive wear of the adhesive). An important note is that with adequate technique, one can avoid both types of failure. In other words, a clinician who experiences discouraging failure rates should reevaluate and improve the technique of making bonded lingual retainers.

Lingual Retainer Adhesives. Different composite resins have been advocated for bonding retainer wires.[45] Unlike the adhesive under a bracket, the lingual retainer resins remain exposed to the oral cavity and therefore require some specific physical properties. Several specific lingual retainer adhesives may offer ease of application, optimal handling, improved patient comfort, and minimal abrasive wear. Recent findings[1] indicate that light-activated composites may have these properties. The amount of total light energy delivered to the composite resin determines hardness, wear resistance, water absorption, residual monomer and its biocompatibility. Recent studies have tested the surface hardness[21] and conversion rate[48] of some different lingual retainer adhesives. Two light-cured adhesives (Transbond LR, 3M/Unitek; and Light Cure Retainer, Reliance Orthodontics) were cured with conventional halogen (Ortholux XT), fast halogen (Optilux 501), and plasma arc (PowerPac, American Dental Technologies, Corpus Christi, TX) light sources and were compared with autopolymerizing diluted or undiluted Concise resin. The following conclusions emerged:

1. Plasma arc and fast halogen lights are quicker alternatives than conventional halogen lights, without compromising final hardness values of the lingual retainer adhesives.
2. Some adhesives may need unexpectedly long curing times with fast curing lights (Light Cure Retainer with PowerPac in this study).
3. Transbond LR yielded significantly higher surface hardness than Concise and Light Cure Retainer, with Concise being significantly harder than Light Cure Retainer.
4. The dilution of Concise resin decreased the in vitro surface hardness, which in turn may decrease its clinical abrasion resistance and longevity.

The authors' ongoing clinical study on lingual retainers bonded with a split-mouth design using Transbond LR on one side and diluted Concise on the other so far has demonstrated equal and excellent success rates. The heat caused by rapid curing with high-intensity lights and shrinkage of the composite resin probably are of little clinical concern for the small amount of resin used when bonding lingual retainers.

Bonding the 3-3 Retainer Bar. The following clinical recommendations (Figure 21-30) represent basic principles that have been tested clinically over many years. Although it may seem possible to take shortcuts, this is strongly discouraged; strict adherence to a meticulous technique has been found to be the key to long-term success:

1. While the orthodontic appliances remain in place, take a snap impression of the patient's teeth and pour a working model of hard stone.
2. Using the working model as a guide, bend a plain round stainless steel or gold-coated wire of 0.030- to 0.032-inch diameter with a fine, straight three-jaw or similar pliers so that the wire precisely contacts the lingual surface of all mandibular incisors (Figure 21-30, *A*).
3. Sandblast the ends with 50 microns of aluminum oxide powder for about 5 seconds from different directions, using the Microetcher (Figure 21-30, *B*) in a dust cabinet.
4. Clean the lingual surfaces of both canines with a tungsten carbide bur (No. 7006) or a large, round diamond bur.
5. Check the position of the wire in the mouth. When optimal, fix with three or four steel ligatures around the bracket wings of the incisors (see Figure 21-30, *C, D*).
6. With retainer wire in place, etch the lingual surfaces of the canines with colored phosphoric acid gel (Ultraetch 35% or Etch-Rite 38% [Pulpdent]) (see Figure 21-30, *E*) for 30 seconds. Rinse and dry completely. Use a high-speed vacuum evacuator. Sealant is not needed on lingual surfaces, partly because of the reduced risk of decalcification. This fast and efficient procedure reduces the risk of moisture contamination.
   A. Chemically cured composite resin (e.g., Concise): Bond the retainer using a two-step procedure.
      a. Tacking: Tack the wire to both canines with a small amount of a flowable light-cured composite resin (e.g., Revolution, Kerr) and cure for 5 seconds (see Figure 21-30, *G*). This initial tacking is vital for strength. Because the wire now cannot be displaced, the bulk of adhesive can be added with a totally undisturbed setting.
      b. Bulk of adhesive: Bond the retainer wire to the right and left canines, applying resin from the gingival margin to the incisal edge with a composite-placement instrument. Check with a mouth mirror to see that enough adhesive is used, and add more composite resin wherever required (often in the mesiogingival and distogingival corners).
   B. Light-cured composite resin (e.g., Transbond LR):
      a. Apply a thin coat of moisture insensitive primer (Transbond MIP) on the sandblasted ends of the retainer wire and on the etched enamel. This will reduce the risk of moisture contamination.
      b. Apply the Transbond LR adhesive to the right and left canines. Shape the resin bulk with fine brush strokes from the gingival margin to the incisal edge. A small amount of Transbond MIP on the brush tip will dilute the composite resin and make it flowable, and this will create a smooth, gentle contour in an incisogingival direction. It takes some experience to find the right consistency. If too much primer is added, the adhesive will drift away from where it is placed and may flow interdentally and contact the gingiva. Optionally, the adhesive may be transferred from a mixing pad. The adhesive on the mixing pad should have a light-impermeable cover.
      c. Light cure the composite resin according to instructions for light source used (e.g., 5 to 10 seconds for LED curing).
7. Cut the ligature wires. Trim (whenever necessary) along the gingival margin and contour the bulk with an oval tungsten carbide bur (No. 7408; see Figure 21-30, *I*) so that it has a smooth contour in an

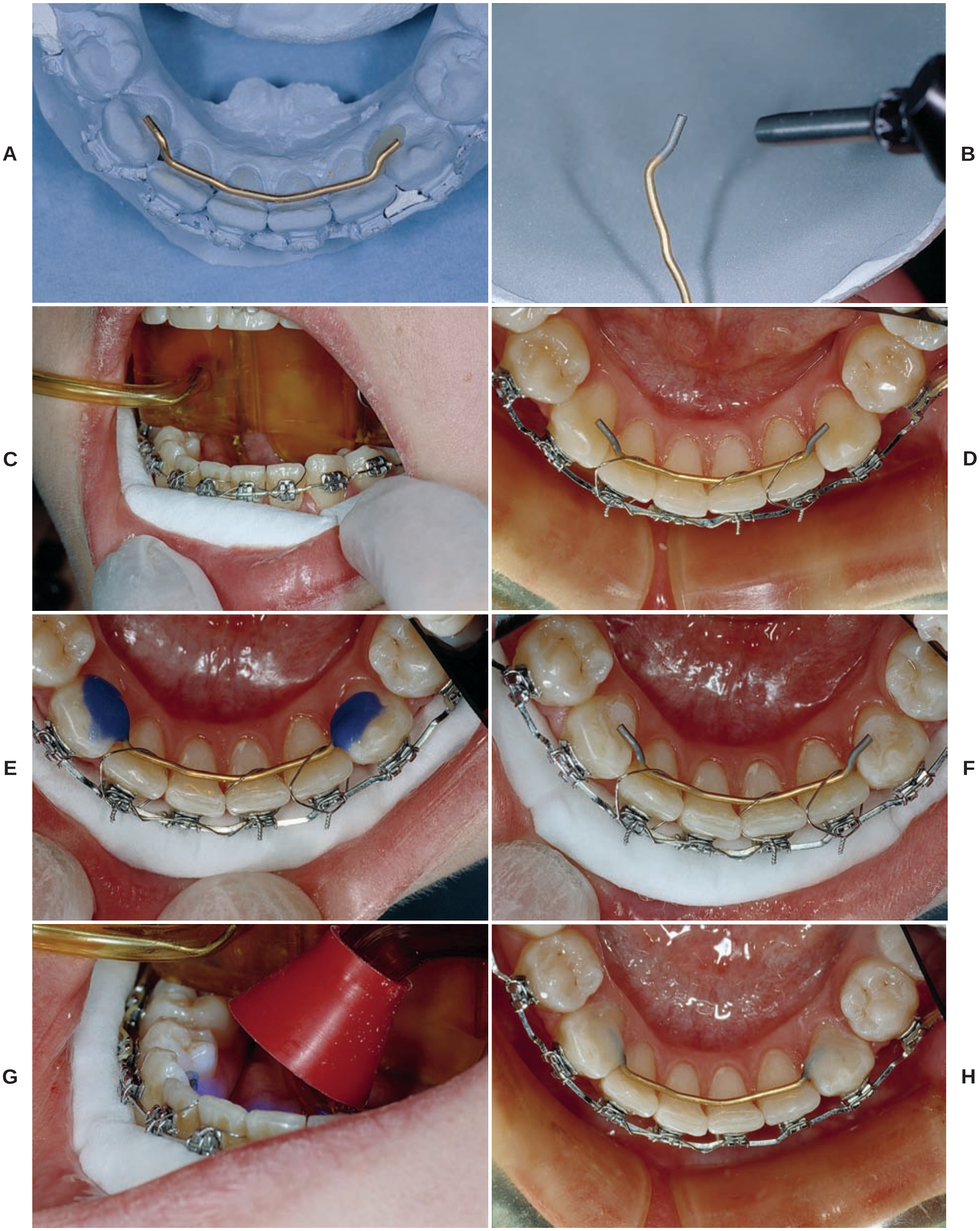

FIGURE 21-30 Making the bonded 3-3 retainer bar. **A,** Careful adaptation of retainer wire on stone model using fine three-jaw pliers. **B,** Sandblasting terminal ends of retainer bar. **C,** Lingual saliva ejector with high bite block (3M/Unitek) secures an optimally dry working field with no interfacing appliances. **D,** The 0.030-inch gold-coated wire is positioned by means of three steel ligatures. **E,** Ultraetch 35% phosphoric acid gel for acid etching. **F,** Treated area clearly indicated. **G,** Initial tacking with small amount of flowable light-cured composite resin. **H,** Bulk of adhesive added to tacked retainer.

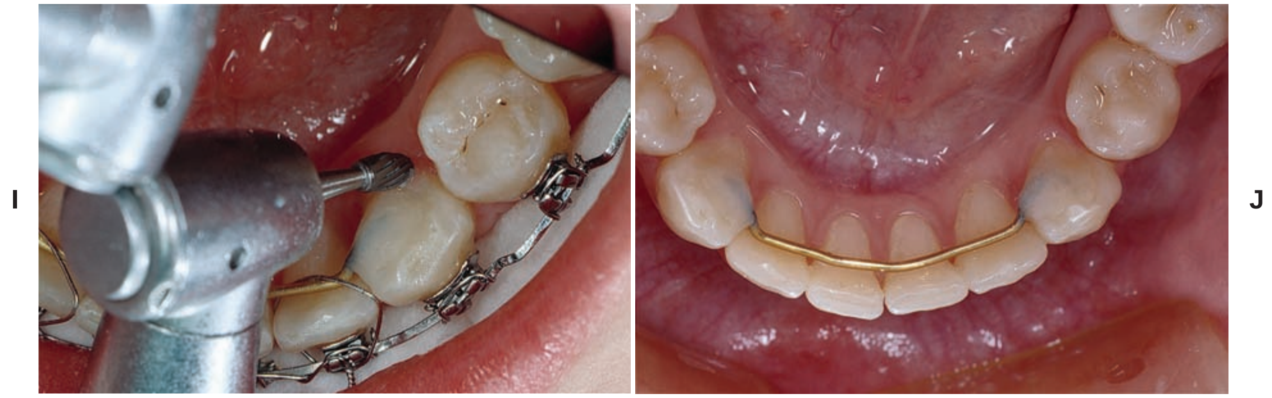

FIGURE 21-30, cont'd **I,** Trimming adhesive with No. 7408 tungsten carbide bur. **J,** Final appearance.

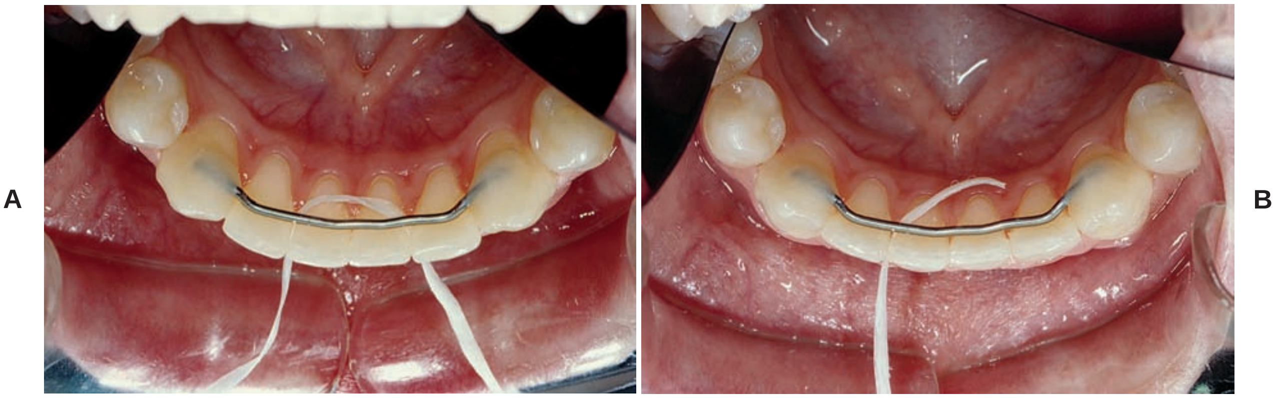

FIGURE 21-31 Interdental cleaning under a bonded 3-3 retainer. **A,** If a floss threader is not available, a loop is formed over two incisors and moved under the retainer bar. **B,** When one end of the floss is pulled in, the other will snap free and can be grabbed with the fingers. Patients are instructed to move the floss over the interproximal surfaces once daily.

incisogingival direction. Use a smaller bur (No. 2) interdentally.

8. Instruct the patient in proper oral hygiene and use of dental floss or Superfloss (Oral-B, South Boston, Massachusetts) beneath the retainer wire and along the mesial contact areas of both canines (Figure 21-31). Instruct patients to floss once daily to prevent accumulation of calculus and plaque.

Long-term Experience. Experience with bonded 3-3 retainer bars over 15 to 20, or more, years is generally excellent, provided a careful bonding technique is used.[45,46,49–51] Particularly, the third-generation 3-3 retainer is a fine mandibular retainer. Not only is the retainer solid, easy to place, and hygienic, but it also appears to be safer than mandibular retainers in which all six anterior teeth are bonded, which is equally important. A patient notices immediately whether a retainer comes loose when it is bonded only to the canines. The patient then can call for a rebonding appointment or remove the retainer if necessary. For several years, a mandibular bar bonded only to the canines has been the authors' preferred retention method in adolescent and many adult patients. However, occasional cases of slight relapse anteriorly may occur when using retainers bonded only to the canines.[50] For this reason, a flexible spiral wire (FSW) retainer bonded to all six anterior teeth (see the following discussion) may be indicated for adult patients with considerable pretreatment crowding.

The senior author's long-term (up to 12 years) experience with third-generation gold-coated 3-3 retainer bars shows excellent outcomes with little loosening.[46] The failure rates are considerably lower than those reported by others,[52] which probably is explained by careful bonding procedures (see Figure 21-30).

Many patients apparently have difficulties keeping the retainer area really clean, despite patient instruction in hygiene. Accumulations of supragingival calculus and stain often are noted along and beneath the retaining wire, whereas decalcification and caries are observed only exceptionally.[45,50] Clinical data indicate no significant difference in plaque and calculus accumulation between round and spiral retainer wires.[49,53] However, the presence of even large amounts of calculus around mandibular retainers is not alarming in young, healthy patients with no periodontal pockets.[54] Gaare et al.[54] compared the effect of toothbrushing after professional prophylaxis in patients with large amounts of calculus (removal requiring an average time of 1 hour per patient) with the effect of toothbrushing as the sole hygiene method. The authors found no significant benefit of the calculus removal, which supports the hypothesis that it is not the calculus but the plaque that forms on it that has pathogenic potential. The effects of calculus accumulations on retainers in adults with existing periodontal problems are unknown at present.

Because the retainers are invisible, a problem may exist in deciding when to remove them. Extended retention periods (up to 10 years, or longer) now are recommended by most clinicians.[1,46,51,55] The long retention periods are favorable in many patients while waiting for the patient's third molars to erupt; long retention counters the effects of postpubertal growth activity and maxillomandibular adjustments, which may continue well into the second decade and longer. As an alternative, the bonded retainer may be replaced after several years with a removable one for long-term or permanent nighttime wear.

Flexible Spiral Wire Retainers

Clinical experience and differential retention philosophy have demonstrated the need for two types of bonded wire retainer:

1. Thick wire (0.030- or 0.032-inch diameter)
2. Thin wire (0.0215-inch diameter)

The thick wire is used for the mandibular 3-3 retainer bar bonded on the terminal dental units only, whereas the thin spiral wire is used for various retainers in which all teeth in a segment are bonded.

In discussing the FSW retainer, the following subdivisions are used:

1. Advantages and disadvantages
2. Long-term experience
3. Technical procedure
4. Repair
5. Indications
6. Conclusions and clinical recommendations

In 1977, the authors' results indicated that bonded retainers using thin multistrand flexible wire (0.015- to 0.020-inch diameter) appeared to be suitable for preventing space reopening in different clinical situations.[45] Long-term (up to 15 or more years) results are now available for different wire types, verifying that the combination of thin spiral wire with wear-resistant bonded composite can provide a very useful mode of retention for a variety of postorthodontic situations[46] (Figure 21-32).

Advantages and Disadvantages. Flexible spiral wire retainers have several advantages:

1. They may allow safe retention of treatment results when proper retention is difficult or even impossible with traditional removable appliances.
2. They allow slight movement of all bonded teeth and segments of teeth. Apparently this is the main reason for the excellent long-term results.
3. They are invisible.
4. They are neat and clean.
5. They can be placed out of occlusion in most instances. If not, the possibility remains of hiding the wire under a slight groove in the enamel.
6. They can be used alone or with removable retainers.

However, FSW retainers have some disadvantages. Good oral hygiene of patients is mandatory. Daily flossing in each interdental space is recommended with the use of a dental floss threader or Superfloss gingival to the wire. The gingival reaction of course also depends on careful removal of excess adhesive at the time of retainer bonding. Side effects in the form of undesirable movement of bonded teeth may occur if the wire is too thin or not entirely passive while bonding.[56,57] Finally, FSW retainers are more subject to mechanical stress and are thus less indicated in deep overbite cases when the wire cannot be placed out of occlusion.[53]

Long-term Experience. Experiments in the late 1970s and early 1980s used different sizes (0.015- to 0.020-inch diameter) and types of multistranded wires.[45] Early findings included the following:

1. The incidence of wire breakage appeared to decrease with increasing wire diameter.
2. Undesirable side effects and tooth movements occurred when short segments of three-stranded 0.015- to 0.0195-inch wire were used.[57]
3. An unacceptable incidence of bond failures occurred when the wires were bonded to the lingual surfaces of premolars.[4,45]

Bond failures and other clinical features of lingually bonded retainers were reported in 1991 by Dahl and Zachrisson.[56] The observation periods were then an average of 6 years for maxillary and mandibular 0.0215-inch three-stranded wire and 3 years for the same diameter five-stranded wire.

The failure rates were considerably lower than those reported in other studies of lingual retainers over periods of 2 to 3 years.[45,50,53] The results with the five-stranded Penta-One wire (Masel Orthodontics, Bristol, PA) were particularly encouraging. The failure rates for loosening were 8% in the maxilla and 6% in the mandible; for wire fracture the failure rates were 3% in the maxilla and were nonexistent in the mandible.[56]

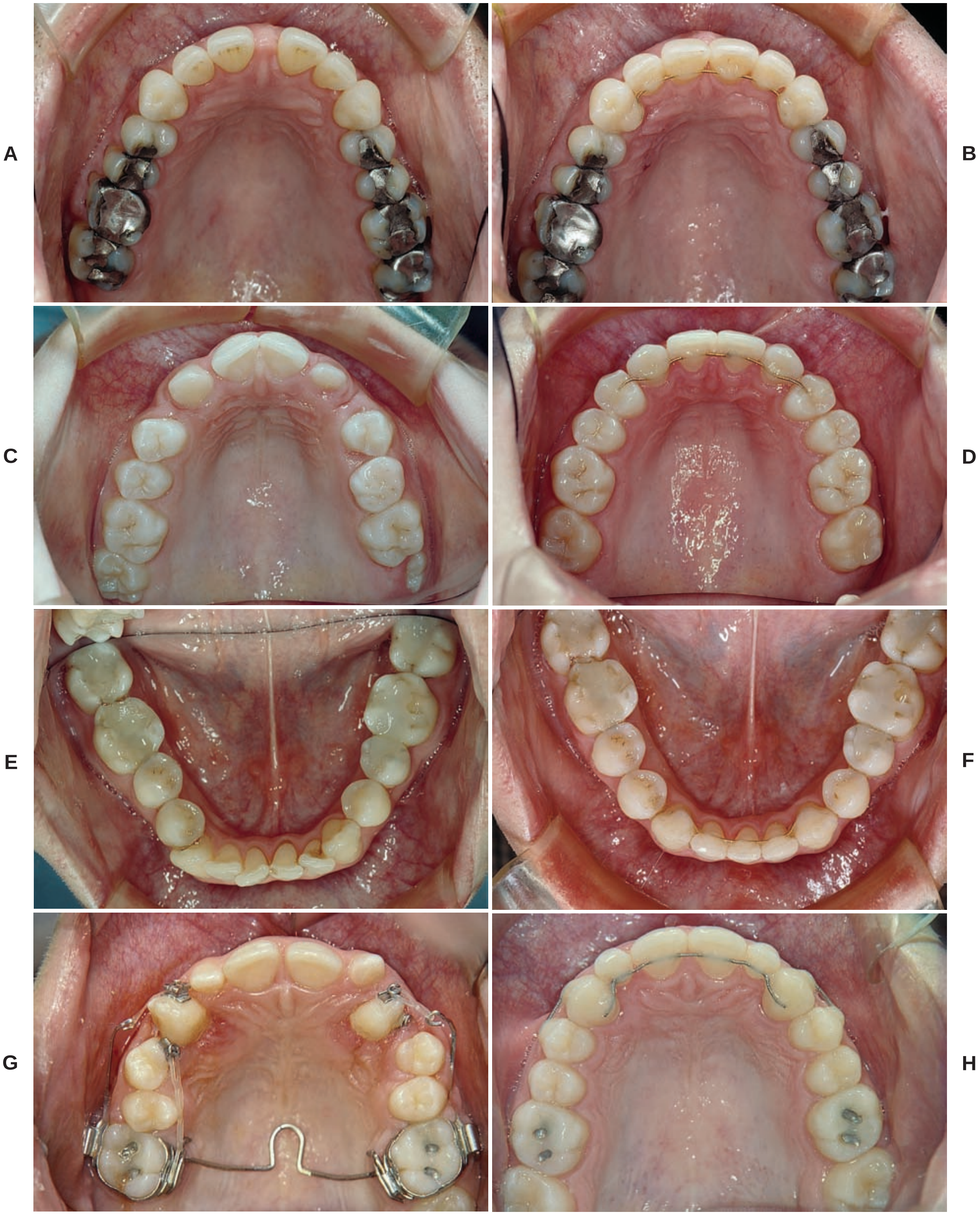

FIGURE 21-32 **A,** Missing lateral incisor case where an acrylic pontic was direct splinted to the central incisor during the orthodontic treatment. **B,** Note braided rectangular wire reinforcement. Four different clinical situations in which a lingual flexible spiral wire retainer is used for improved retention. The cases represent significant midline diastema of maxillary central incisors **(A, B),** bilaterally missing maxillary lateral incisors **(C, D),** one lower incisor extraction in Class III plus open-bite tendency case **(E, F),** and two palatally impacted maxillary canines **(G, H).** In **D,** the six-unit retainer is bonded in the occlusal fossa of the first premolars, whereas in **H**, a short labial retainer is used bilaterally to stabilize the mesially rotated and palatally displaced canines and the distally rotated first premolars.

Since 1994 the senior author has used a gold-plated version (Gold'n Braces) of the five-stranded Penta-One wire exclusively and has observed few failures.[28] The mechanical properties of the stainless steel and gold-coated wires are identical, but the latter is preferred because it is (1) more elegant and (2) gives less darkening shine-through effect on transparent incisors.

The discrepancies between the authors' experience and that of other studies probably can be explained by fewer occlusal interferences (with less contact with opposing teeth to allow for more wear) and by technical factors (such as adequate buccolingual width of composite over the wire, smooth contouring of the adhesive, completely undisturbed setting of the adhesive in every case, and careful adaptation of the wire to the lingual contours of the teeth). The reduction of wire breakage compared with earlier results is related to the increased flexibility of five smaller wires occupying the same diameter as the three larger wires in previous retainers. Because a common mode of failure with bonded FSW retainers is abrasion of composite and subsequent loosening of bonds between wire and composite,[53] one is advised to avoid occlusal contact or to add a thick layer of adhesive over the wire. Even in the absence of tooth contact, such as in the mandible, mechanical forces (tongue activity, toothbrushing) may cause notable abrasion over the years.

Patient acceptance of the FSW retainer is excellent.[46,52,56] In addition, adults especially appreciate that the stability of the treatment result does not depend on their cooperation, which is the case when removable retainers are worn continuously or are worn at night.

When patients with previous multiple spacing of anterior teeth were in the retention phase of treatment, it often was found that after about 6 months small spaces (1 to 2 mm) opened distal to the terminal ends of the retainer wire. Because these spaces apparently did not open further, it was concluded that they illustrated a settled occlusion with the FSW retainer in place in a new state of physiologic equilibrium.[45,52,56] Depending on the occlusion and the patient's dental awareness, such spaces could be filled with mesiodistally extended fillings or crowns or could be allowed to remain.

At present, little is known about the length of time that the bonded FSW retainer should be left in place. The type of original malocclusion and the patient's age and ability to keep the retainer clean may be decisive factors. As long as the retainer is intact, the treatment result is maintained; and as long as the patient performs adequate plaque control, no real reason exists to remove the retainer.

Accumulations of calculus in mandibular FSW retainers may not be alarming.[50,54] In selected cases, retainers may be used for permanent stabilization.[46,50] Advanced periodontal cases probably need permanent retention (Figure 21-33). Further follow-up research is needed for semipermanent and permanent use of bonded retainers. As discussed for the 3-3 retainers, in some cases it may be practical to use the bonded lingual retainer for a prolonged retention period and then to replace it with a removable retainer for nighttime wear on a more permanent basis.

Bonding Flexible Spiral Wire Retainer. The following clinical direct-bonding procedure is advocated for bonding with chemically or light-cured composite resin, respectively (see Figures 21-34 to 21-36):

1. Toward the end of orthodontic treatment, take a snap impression and pour a working model in stone.
2. Using fine, three-pronged wire-bending pliers and marking pen, adapt the 0.0215-inch Penta-One steel or gold-coated wire (Gold'n Braces) closely and passively to the crucial areas of the lingual surface of the teeth to be bonded. Cut the wire to the required length.
3. Check the retainer wire in the mouth for good fit in an entirely passive state and adjust if necessary.
4. Clean the surfaces to be bonded with a tungsten carbide or diamond bur and etch with phosphoric acid gel (Ultraetch or Etch-Rite) (see Figure 21-35; see also Figure 21-34) for 30 seconds.
   A. Chemically cured composite resin (e.g., Concise):
      a. Use a four-handed approach (or similar) for initial tacking (see Figure 21-34, *C–E*). Hold the wire by hand in the optimal position while tacking it to one incisor with a small amount of flowable light-cured composite resin (e.g., Revolution). Check the wire for passive tension after tacking (see Figure 21-34, *E*). If the wire is passive, tack the remaining teeth; if not, remove the wire and start over. The initial tacking is vital to securing wire passiveness and optimal bond strength because the tacked wire cannot be displaced and cause disturbed setting when the bulk of adhesive is added. Check with a mouth mirror to be sure that enough adhesive is used (see Figure 21-34, *F*). Add more adhesive whenever it is required. It is important for strength that the adhesive covers a large buccolingual area over the wire.
      b. Contour the bulk of adhesive and remove any excess along the gingival margin. Use oval tungsten carbide burs (No. 7006 and No. 7408) to obtain correct amount and contour of adhesive (see Figure 21-34, *G, H*), and remove adhesive interdentally with small, round burs (No. 1 and No. 2; see Figure 21-34, *I*).
   B. Light-cured composite resin (e.g., Transbond LR):
      a. Use a four-handed approach (or similar) for the initial tacking. Hold the wire by hand in the optimal position while tacking it to one incisor with a small amount of Transbond LR (see Figure 21-35, *E, F,* and 21-36, *B*). Check

the wire for passive tension after tacking. If the wire is passive, add more adhesive and light cure the remaining teeth; if it is not, remove the wire and start over again.

b. Contour the bulk of adhesive with the brush dipped into the primer. Optionally, transfer the adhesive from a mixing pad, which should have a light-impermeable cover. That the adhesive cover a large labiolingual area over the wire is important for strength and wear resistance. Trim with burs when necessary.

5. Instruct the patient in proper oral hygiene and use of dental floss and in each interdental area with a floss threader or Superfloss.

Indirect Bonding of Flexible Spiral Wire Retainer. The fixed lingual retainer also can be fabricated with an indirect technique as described elsewhere.[58] A practical approach for lingual retainers is to use indirect bonding with a 2-mm-thick polyethylene thermoplastic transfer tray and Transbond LR and Sondhi Rapid Set as adhesive resins.[58]

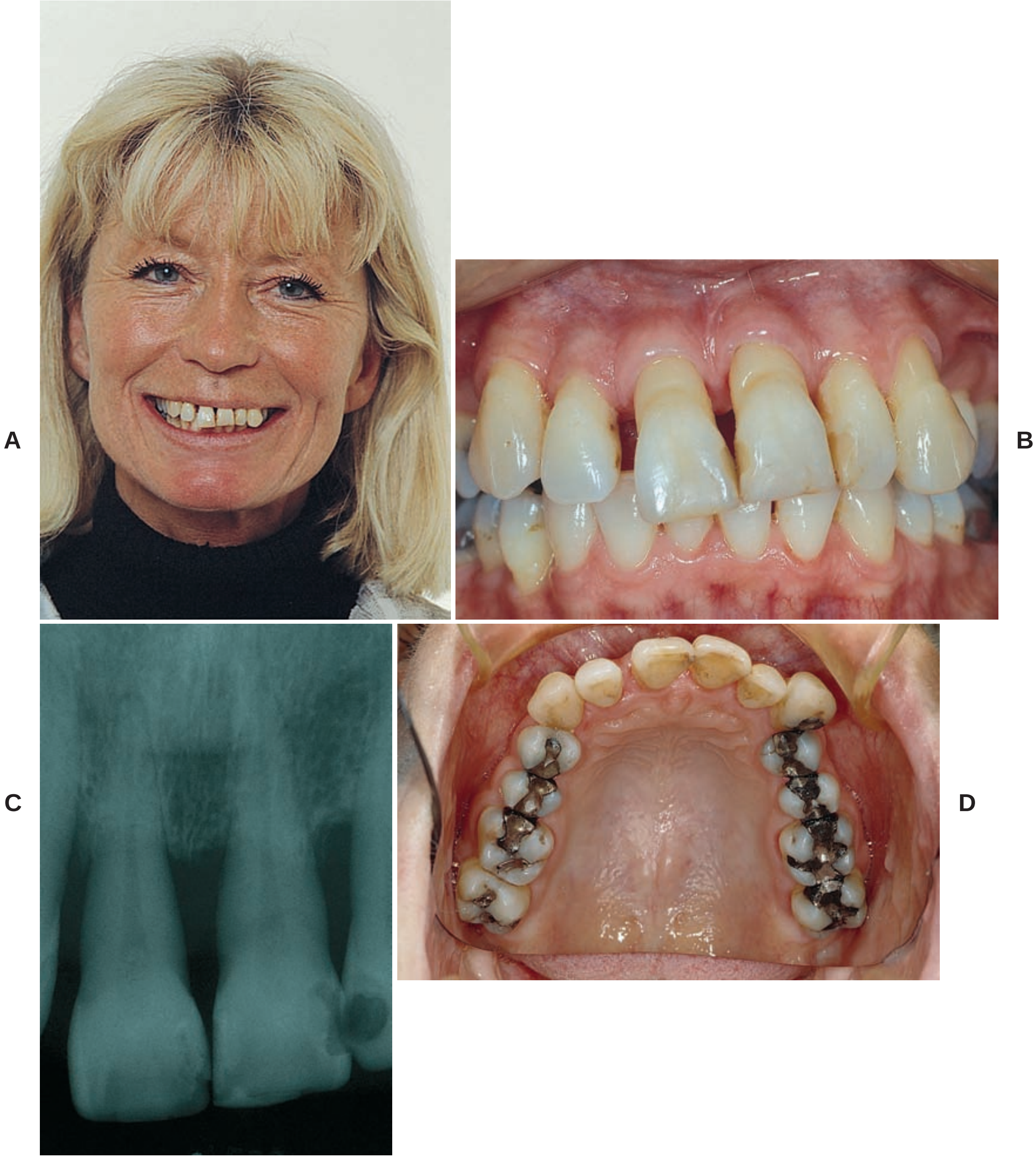

FIGURE 21-33 Adult female patient with advanced hard and soft periodontal tissue destruction and pathologic migration of the maxillary anterior teeth before **(A–E),** during **(F),** and after **(G–J)** orthodontic treatment.

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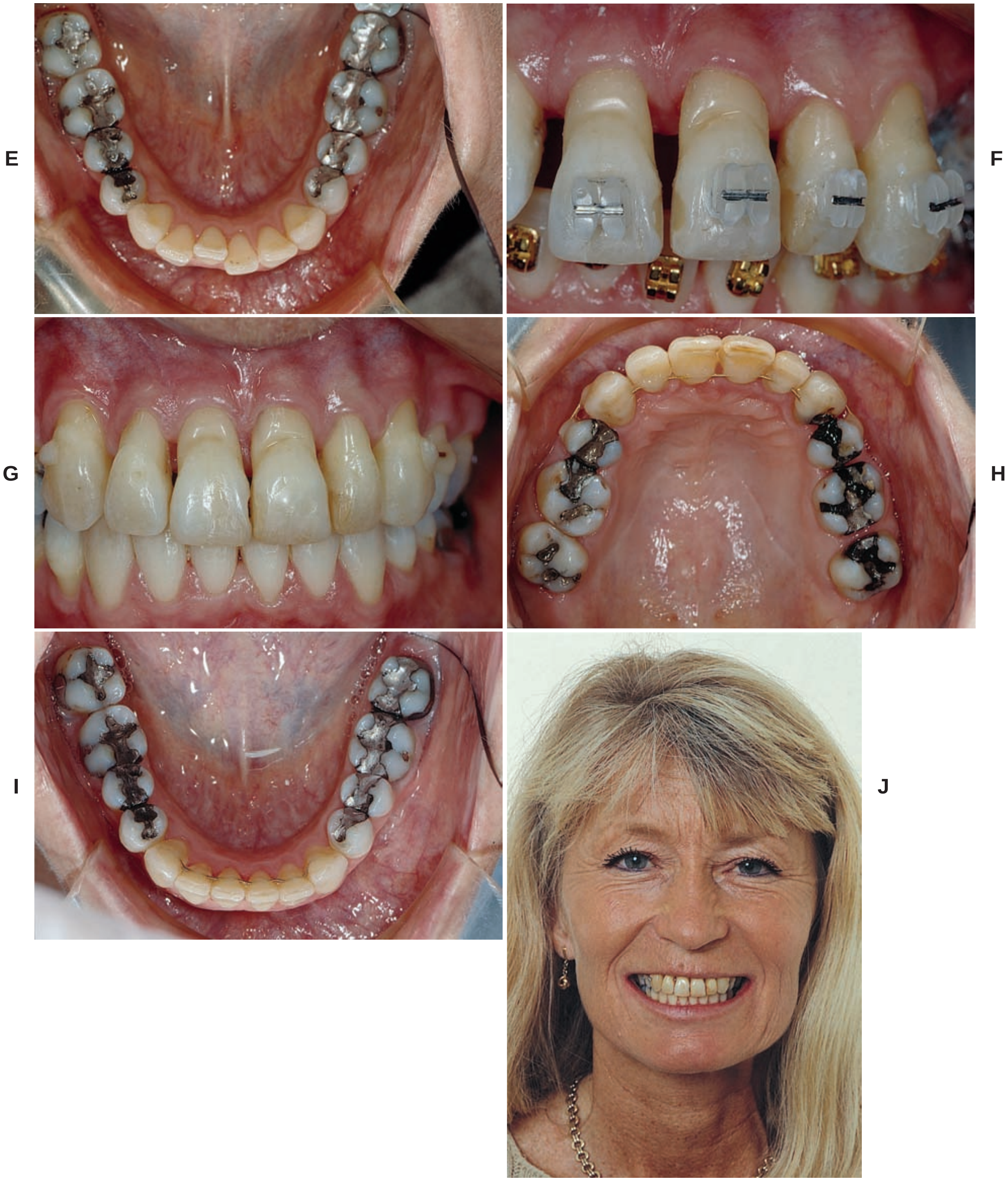

FIGURE 21-33, cont'd The improved dental result is retained by means of six-unit bonded lingual retainers in both dental arches **(H, I).** Some interdental gingival recession was unavoidable in the maxillary anterior region, but it does not show much clinically **(J).** The radiographs after treatment showed no progression of periodontal tissue destruction compared with the initial films **(C).**

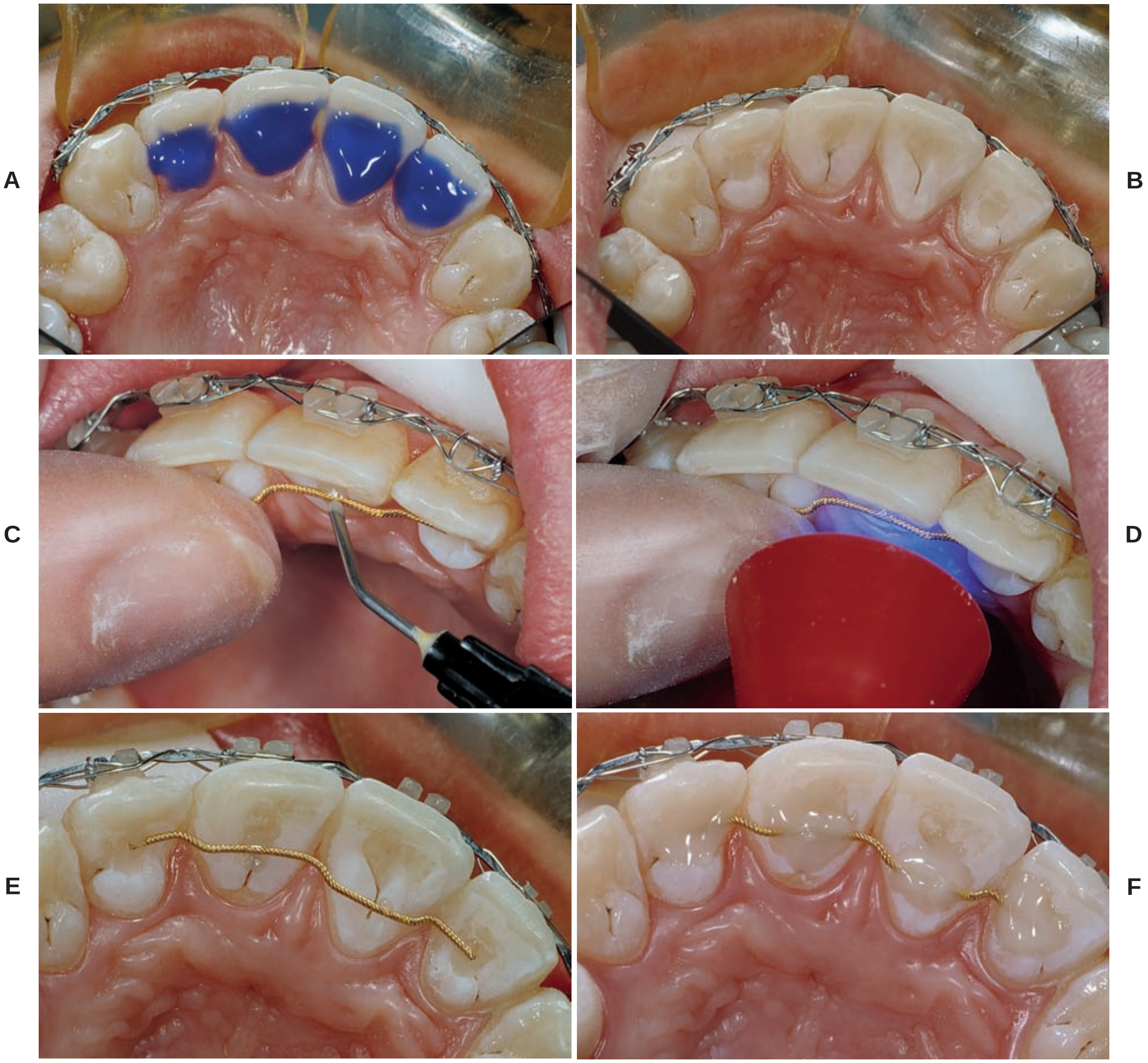

FIGURE 21-34 Fabrication of four-unit flexible spiral wire retainer with chemically cured composite resin. A gold-coated Penta-One wire is adapted carefully on a model with fine three-jaw pliers to fit the lingual contours of the incisors passively. **A, B,** Acid etching of the lingual surfaces of the upper incisors. **C, D,** The initial tacking to one incisor is made with flowable light-cured resin, with the wire held in the optimal position by a finger. This initial tacking to one tooth allows direct checking of position and fit of the retainer wire and is the key to avoid unwanted tooth movement as a side effect during the retention period. When correct and passive, the remaining teeth are tacked next with a small amount of light-cured flowable resin **(E)** before the bulk of adhesive is added in a gingival-occlusal movement **(F).**

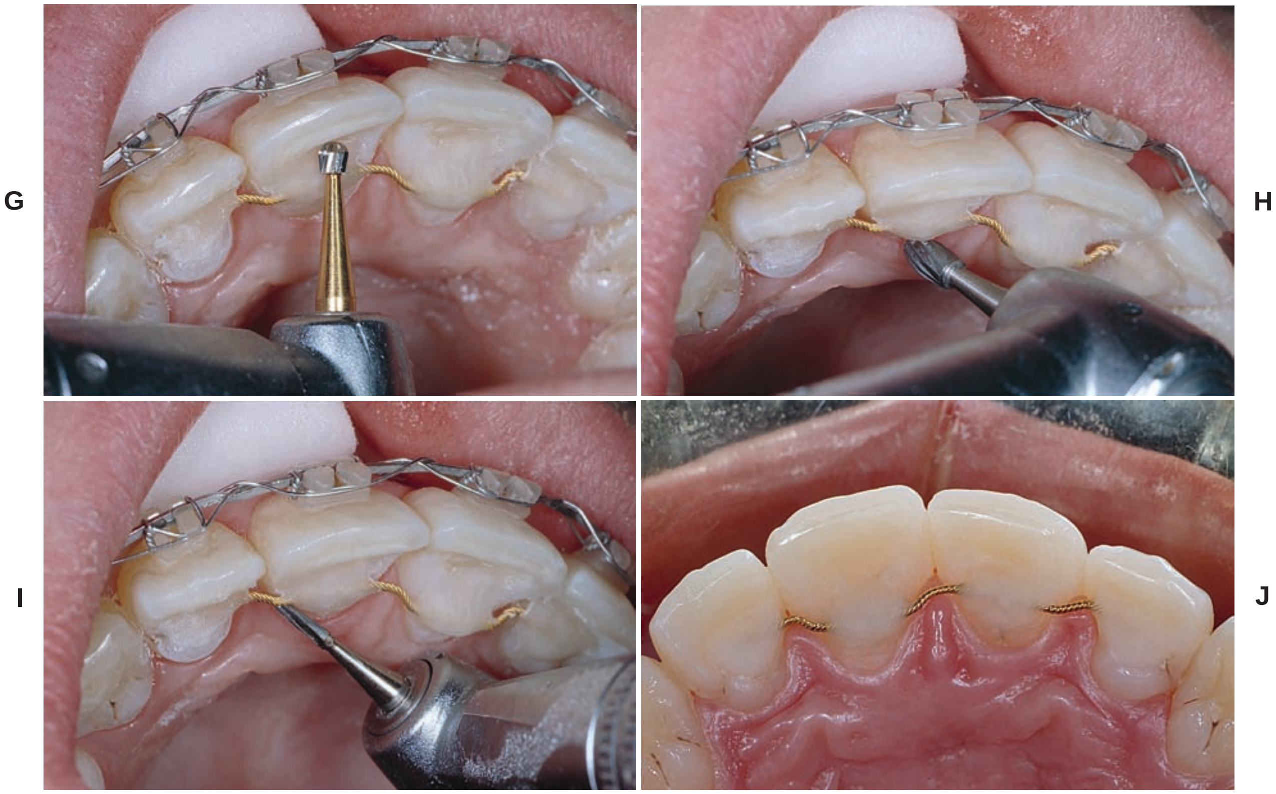

FIGURE 21-34, cont'd A thin mix of composite resin then is added with an explorer to fill in the bond mesially and distally on each tooth. Trimming is made with tungsten carbide burs **(G–I).** The No. 7006 bur is ideal incisal to the wire to avoid occlusal interference, whereas the contour gingival to the wire is made with the No. 7408 bur. **J,** Final result.

Repair. The most common problem following wire fracture or the loosening of the bonding site(s) in FSW retainers is unwanted movement of one or more teeth. At this stage, the teeth are not seated firmly in their sockets and therefore generally can be forced back into position using techniques such as heavy pull with one or two steel ligatures (Figure 21-37, *A, B*).

When the repair is made, a temporary contact splint using composite resin or a temporary bonded labial wire has proved to be of considerable value. The latter normally provides better stability and allows a good working area with undisturbed setting of the repair adhesive (Figure 21-37, *C, D*). After the repair, the temporary labial wire (or contact splint) is removed with tungsten carbide burs.

Indications. At least two indications or suggestions are useful for using bonded FSW retainers:

1. Prevention of space reopening
    a. Median diastemas
    b. Spaced anterior teeth
    c. Adult periodontal conditions with the potential for postorthodontic tooth migration
    d. Accidental loss of maxillary incisors requiring the closure and retention of large anterior spaces
    e. Mandibular incisor extractions
2. Holding of individual teeth
    a. Severely rotated maxillary incisors
    b. Palatally impacted canines

In these and other situations the bonded thin spiral wire retainer can be used alone or with a removable retainer. Some details of specific interest relative to the retention in this list of treated malocclusions are discussed briefly.

Closed Median Diastemas. The bonded FSW retainer is ideal for short- or long-term retention of closed median diastemas. The 0.0215-inch five-stranded wire should be bonded preferably over four units (Figures 21-38 and 21-39) to reduce the risk of untoward side effects.[56]

Multiple Spacing of Anterior Teeth. Unimaxillary or bimaxillary spacing of teeth in adolescents and adults is generally easy to treat but difficult to retain. The tendency for space reopening may be great, even despite long periods of retention with conventional appliances. For this reason, a number of experimental approaches have been reported recently, including the use of splints, staples, and mesh.

None of these methods seems to have gained a wide acceptance, however.

Periodontal Conditions with Tooth Migration. The bonded FSW retainer is well suited for stabilizing and

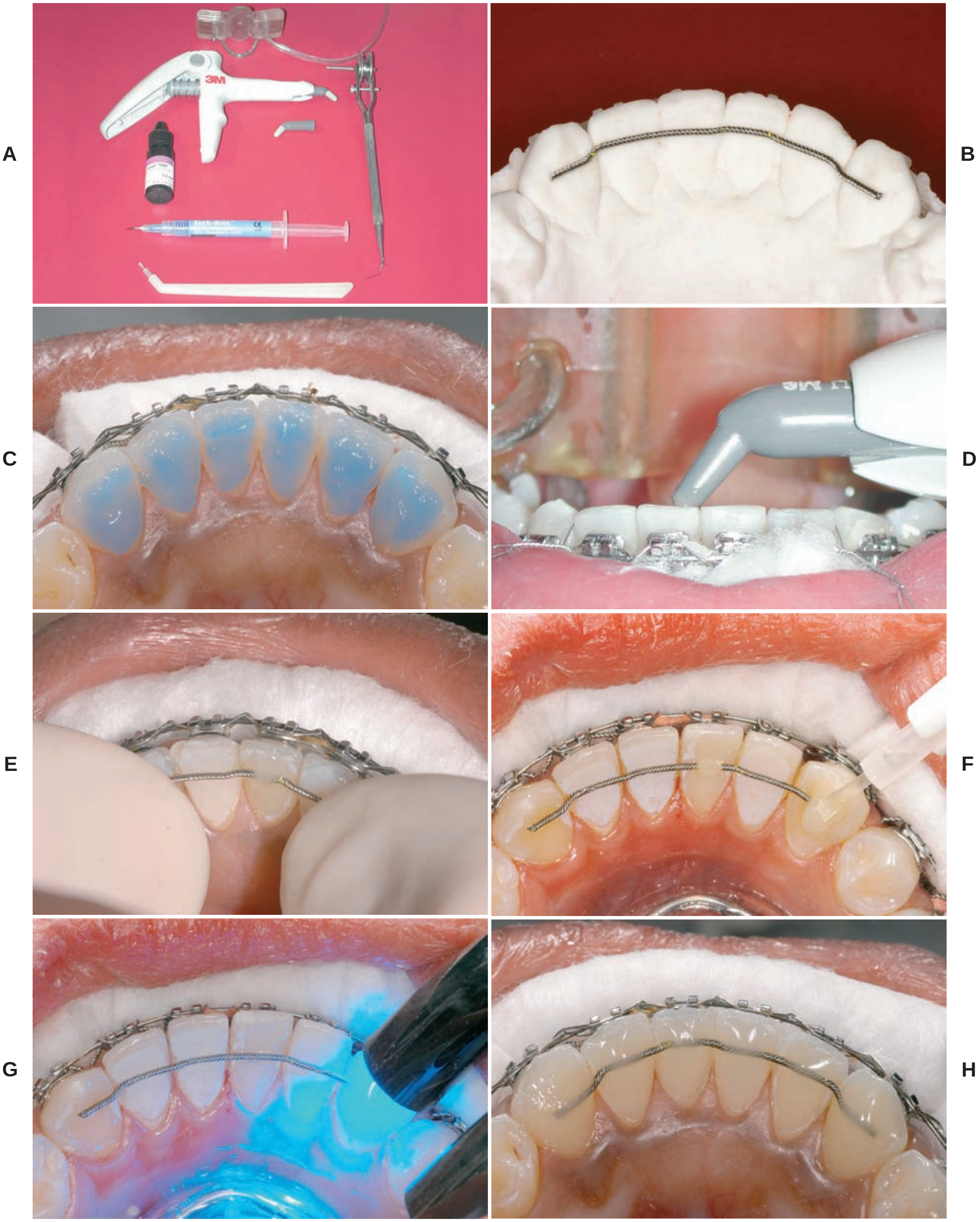

FIGURE 21-35 Instruments **(A)** and method **(B–G)** for fabrication of six-unit lingual flexible spiral wire retainer with light-cured composite resin. After a 0.0215-inch stainless steel or gold-coated Penta-One wire is adapted for optimal fit on the lingual surfaces of all teeth **(B),** the teeth are acid etched with phosphoric acid gel **(C).** Composite resin is added to one incisor **(D, E)** and light cured. After a check that the wire is passive and has a good fit to the remaining teeth, composite resin is added, shaped with the aid of liquid resin and fine brush **(F),** and light cured **(G). H,** Final result.

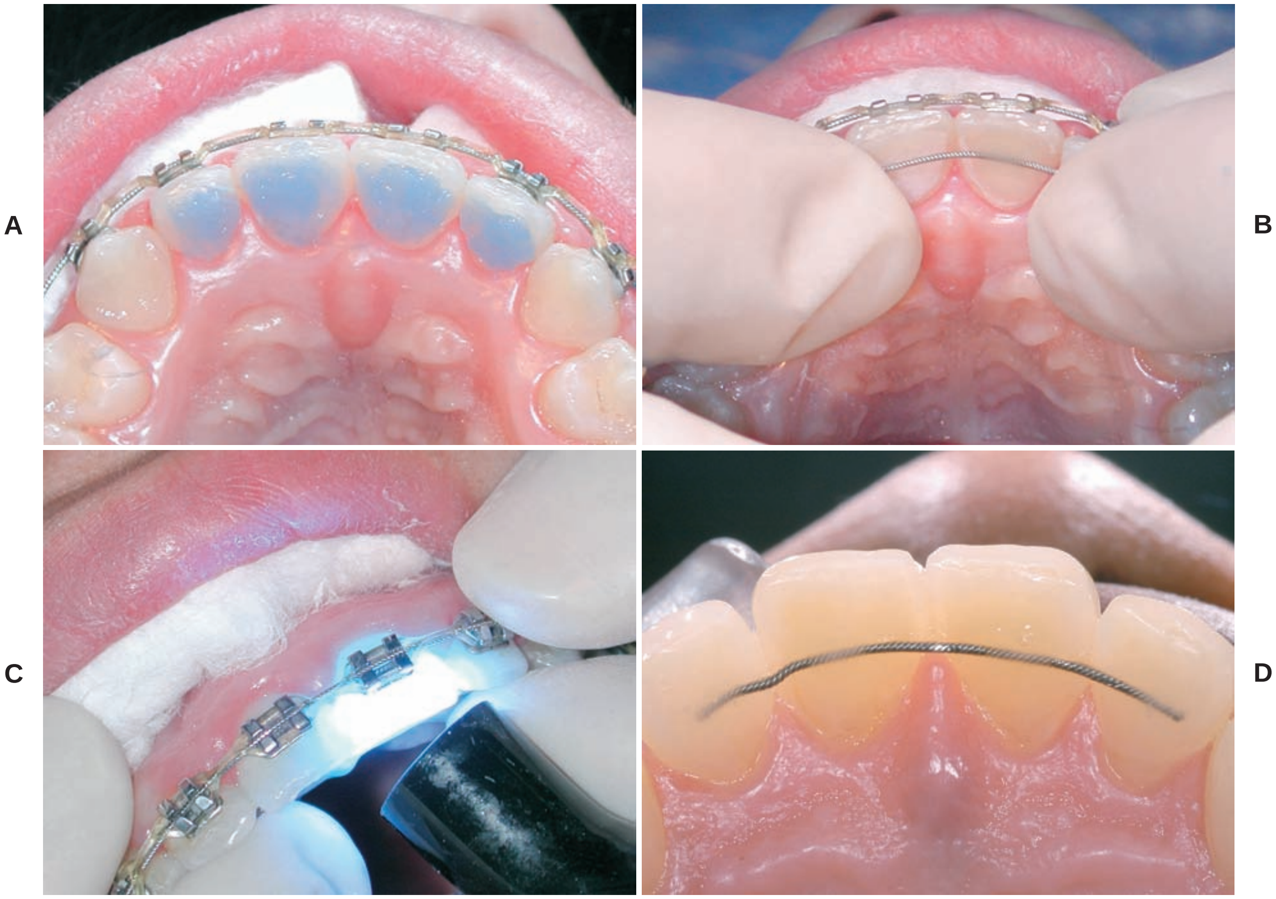

FIGURE 21-36 Fabrication of four-unit flexible spiral wire retainer with light-cured composite resin. **A,** Etching with phosphoric acid. **B,** Finger-holding of wire while tacking one incisor. **C,** Light curing the remaining teeth. **D,** Final result. See text for details.

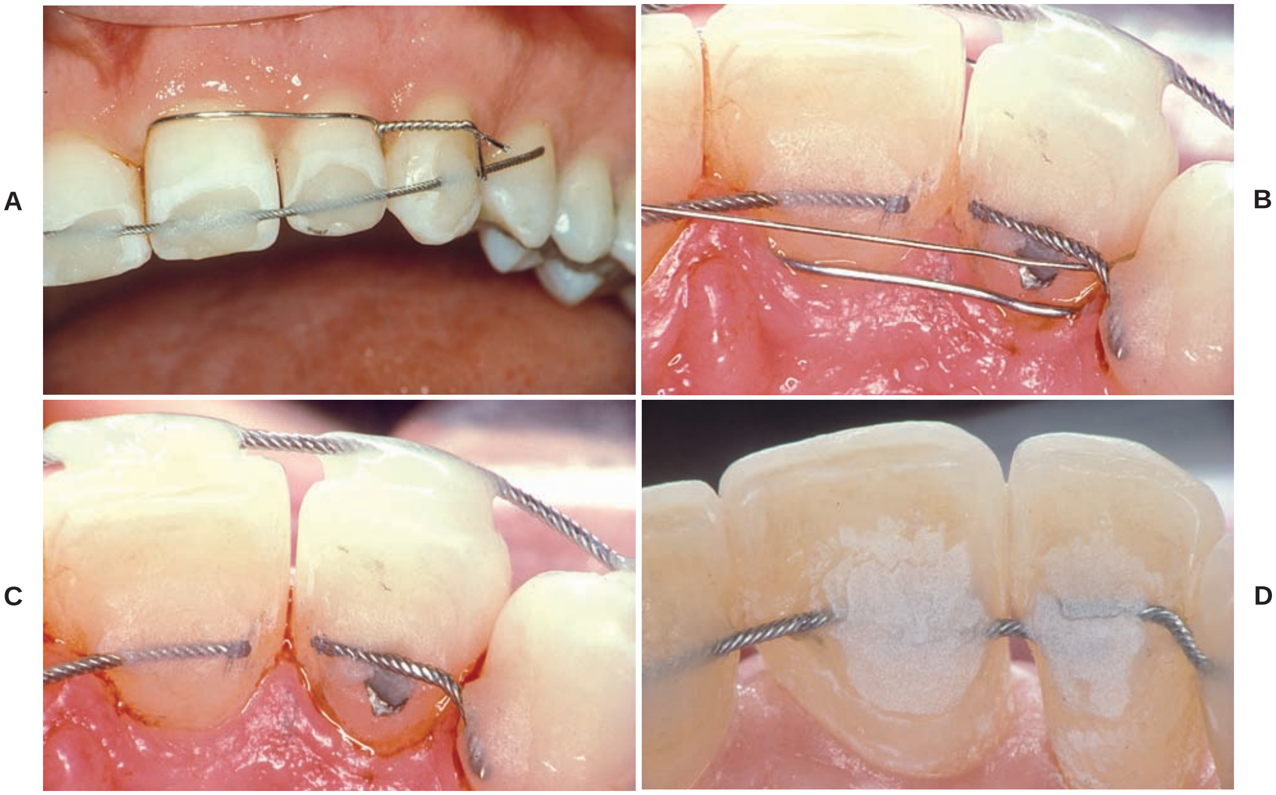

FIGURE 21-37 Repair of broken retainer (fatigue fracture of wire between left central and lateral incisor), using labial temporary wire for stabilization during rebonding. When the loose teeth have been pulled together with steel ligatures **(A, B)** to close a small space, the temporary wire is bonded labially with adhesive after a 5-second etch. After setting, the steel ligatures can be removed to provide a nice working field **(C),** where the repair wire can be bonded with no disturbed setting gingival to the main retainer wire **(D).**

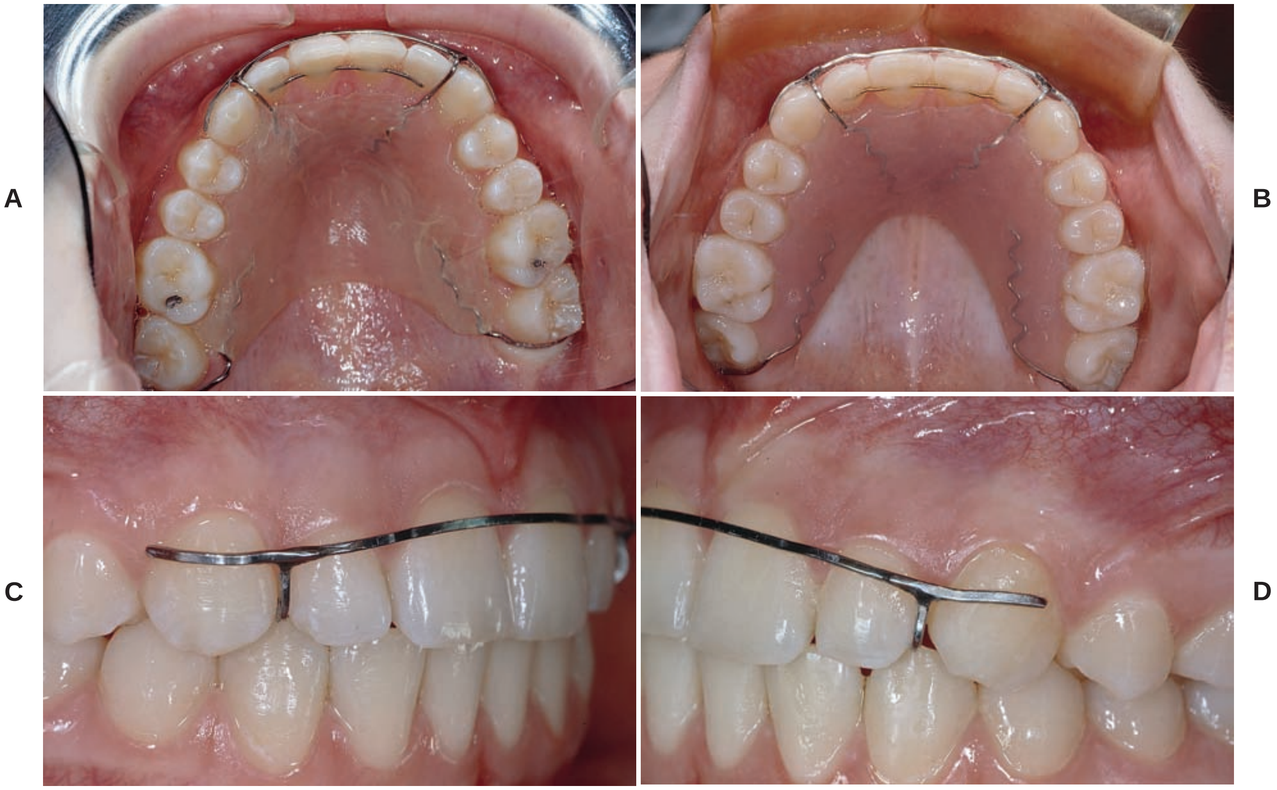

FIGURE 21-38 Recommended version of removable plate to be used with a four-unit bonded lingual retainer. The rectangular (0.019 × 0.026 inch) labial wire of this plate extends distal to the lateral incisors and has a soldered extension wire to prevent flaring of the canines. A holding clasp of 0.8-mm round wire is distal to the second molars.

maintaining teeth into their new position after orthodontic treatment of adults with periodontal problems[55] (see Figure 21-33). The main advantage over removable retainers worn part time is that jiggling is avoided. The FSW also may be used for periodontal splinting when teeth exhibit increased mobility or when the mobility is of a magnitude that disturbs masticatory function or patient comfort.

Recently, extracoronal splinting using acid etching and composite resins has been suggested, alone or incorporating ligature wire, a perforated cast form, fiberthread or fiberglass, or grid material. Direct contact splinting is not durable enough; composite over wire ligation creates unnecessary bulk and compromises aesthetics; and the cast splints require expensive and time-consuming techniques.

To reduce failures in terms of wire fracture (Figure 21-40) or loosening, it is important that the patient try to avoid biting on a bonded maxillary retainer. In some instances, a deep overbite will result only in abrasive wear of the composite and wire without loosening. However, several studies indicate that direct biting on the retainer wire is the most common reason for retainers coming loose.[53] Following abrasion of the adhesive, loosening occurs between composite and the wire. Thus in cases of deep overbite, bonding the retainer wire gingivally to the contact line (Figure 21-41) or, if this is not possible, hiding the wire in a small groove in the enamel is recommended.

Accidental Loss of Maxillary Incisor(s). Most accidents in which maxillary central incisors are knocked out of the mouth occur in the age period from 8 to 10 years.

When orthodontic space closure is selected as the treatment alternative, the canines and premolars frequently have not yet erupted, and a two-stage orthodontic treatment is indicated. In the first stage the lateral incisors are brought mesially to prevent bone resorption and allow mesially directed eruption of the canines. Then 1 to 3 years must pass until all permanent teeth have erupted, at which time the second stage of orthodontics can be performed. When removable retainers are used in the waiting period between the two stages, more often than not the patient perceives the experience as a prolonged and tiring orthodontic treatment over too many years. The FSW retainer is excellent in these situations. When the FSW retainer is bonded to the lingual surfaces of the approximated lateral incisors, the patient soon forgets about its existence, and consequently the patient is fresh and cooperative when the final stage of orthodontics begins. Of course, a similar approach can be chosen in other two-stage operations.

Mandibular Incisor Extractions. Sometimes one or two lower incisors are extracted as part of orthodontic

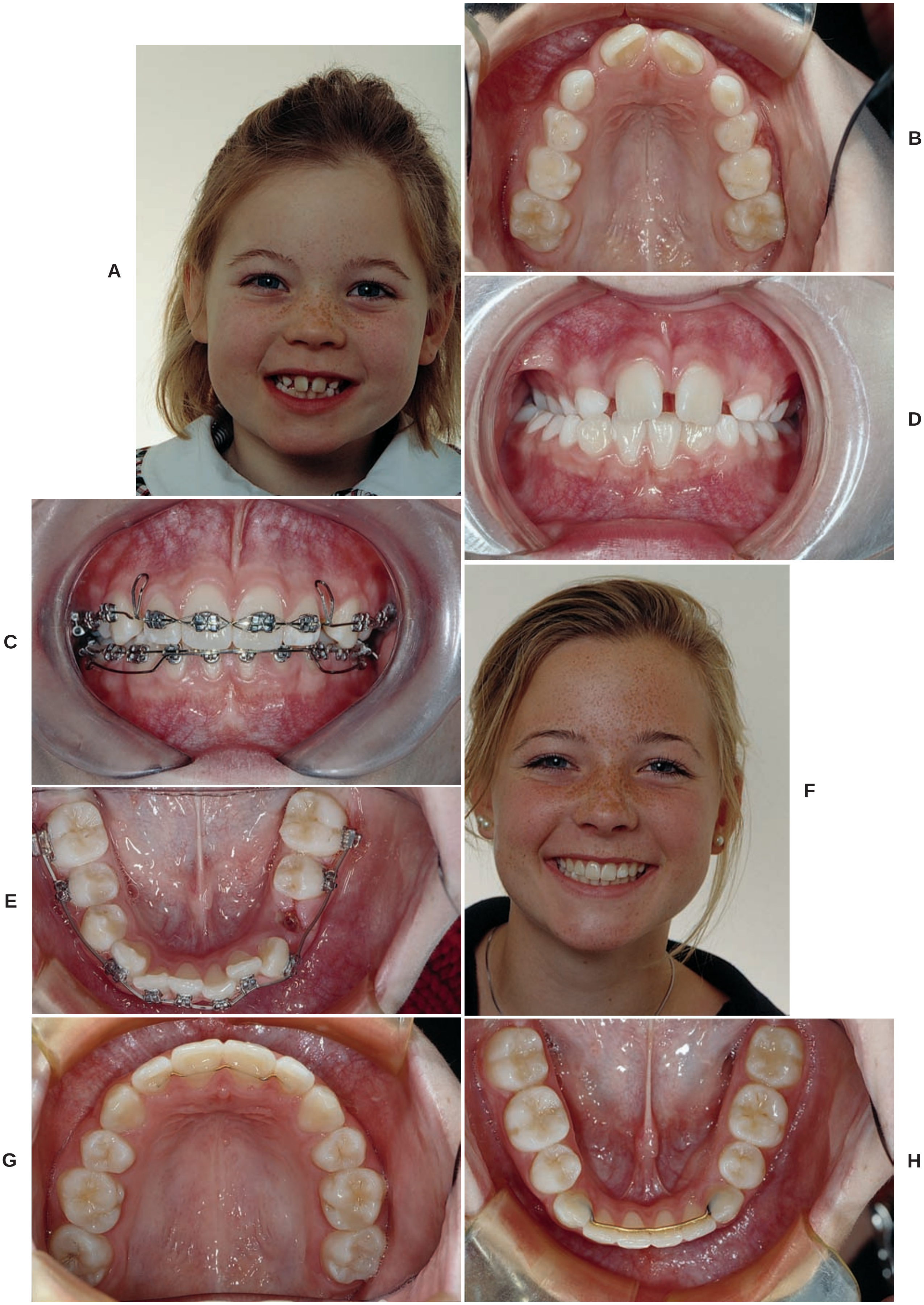

FIGURE 21-39 Recommended routine retention for adolescent patients. Young girl with unilateral crossbite **(A–C)** after orthodontic treatment involving four premolar extractions **(D, E). F,** After treatment. Retainers include an upper four-unit flexible spiral wire retainer **(G)** a lower 3-3 bar **(H),** and a removable plate (see Figure 14-65 for design).

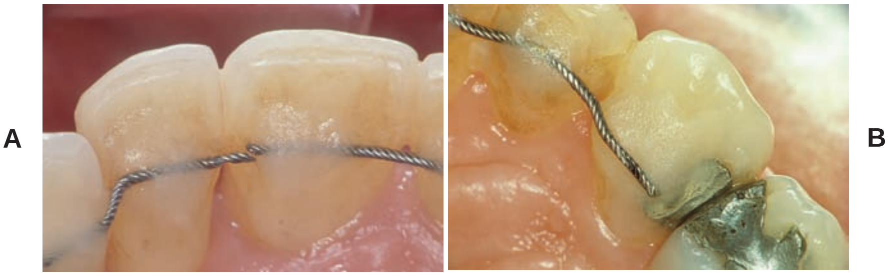

FIGURE 21-40 Fatigue fracture of a lingual retainer wire. **A,** A wire fracture has occurred between the right lateral and central incisors. **B,** Significant abrasive wear of a bonded lingual retainer in the maxillary left canine area caused by occlusal contact with the mandibular canine. The round wire has been worn flat. When a state of equilibrium is reached, such retainers still may be kept in place for several years because of the retentive potential of the wire spirals.

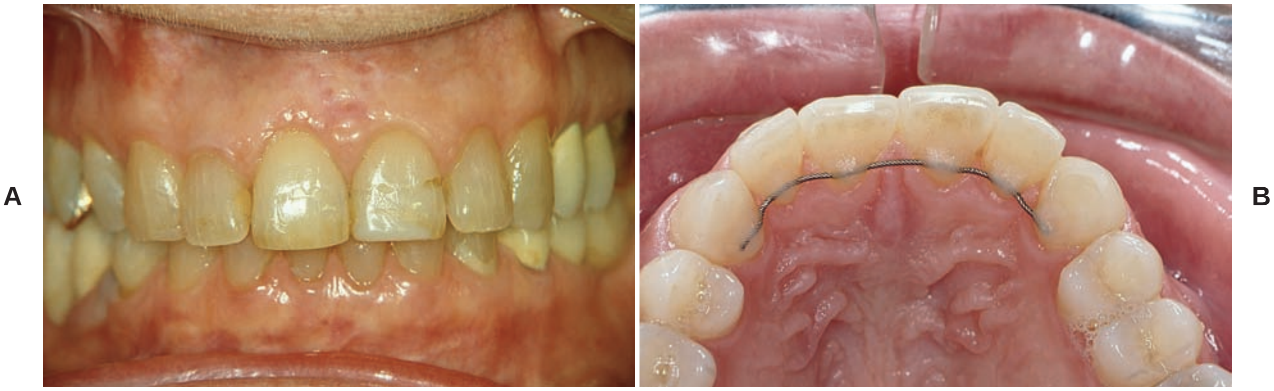

FIGURE 21-41 **A,** If a deep overbite situation remains after treatment, the risk of loosening of a bonded lingual retainer is obvious. **B,** To avoid occlusal interference, the retainer wire may be bonded gingival to the contact line.

treatment.[59,60] This may be true in some adult patients and in patients with an open-bite Class III tendency or a periodontal problem involving excessive gingival recession on the most protruding incisor. Whatever the reason for the extraction, clinical experience indicates a high risk for space reopening with conventional retainers, whether removable plates or fixed 3-3 retainers. By contrast, an FSW retainer bonded to the three remaining incisors (or extended farther distally; see Figure 21-32, *F*) safely maintains the treatment results for as long as it is kept in place.

Rotation of Maxillary Incisors. A well-known clinical problem is that severely rotated maxillary incisors in different types of malocclusion have a great tendency to relapse. This is particularly undesirable because the upper anterior region is the most aesthetically important one for the patient.

Several techniques can be used to improve the stability, including overrotation, fiberotomy, and extended retention periods. Still another aid may be the placement of a bonded FSW retainer.

Whenever a removable plate is used in the maxilla together with a bonded six-unit retainer, the version shown in Figure 21-42 is recommended.

21-12 Retainer. The FSW retainer also can be bonded to the four mandibular incisors as an alternative to a bonded 3-3 retainer. The indications are primarily when the operator is uncertain of the optimal intercanine distance or wants canines to settle undisturbed for other reasons. However, because the long-term results are excellent for six-unit mandibular retainers,[56] little reason exists to use the four-unit solution.[1]

Palatally Impacted Canines. Canines that have erupted into the palate also may display great relapse tendency in a lingual direction, particularly when no interlocking lateral overbite is present. In such instances an FSW retainer bonded to the lingual or buccal of the teeth has proved to be an excellent retainer (see Figure 21-32, *G, H*). The main advantage of the FSW retainer is that it allows more undisturbed bone and soft tissue healing over long periods than can be obtained with removable retainers.

Conclusion and Clinical Recommendations. When it comes to finding simple, reliable, and neat retainers and splints for a variety of clinical situations, the bonded FSW retainer opens up a range of new possibilities. The one limitation to its design and use in difficult or unusual circumstances is the imagination and alertness of the operator. Clinical experience with the FSW retainer over the past 20 years has been excellent when a meticulous technique was used; otherwise, results can be discouraging.

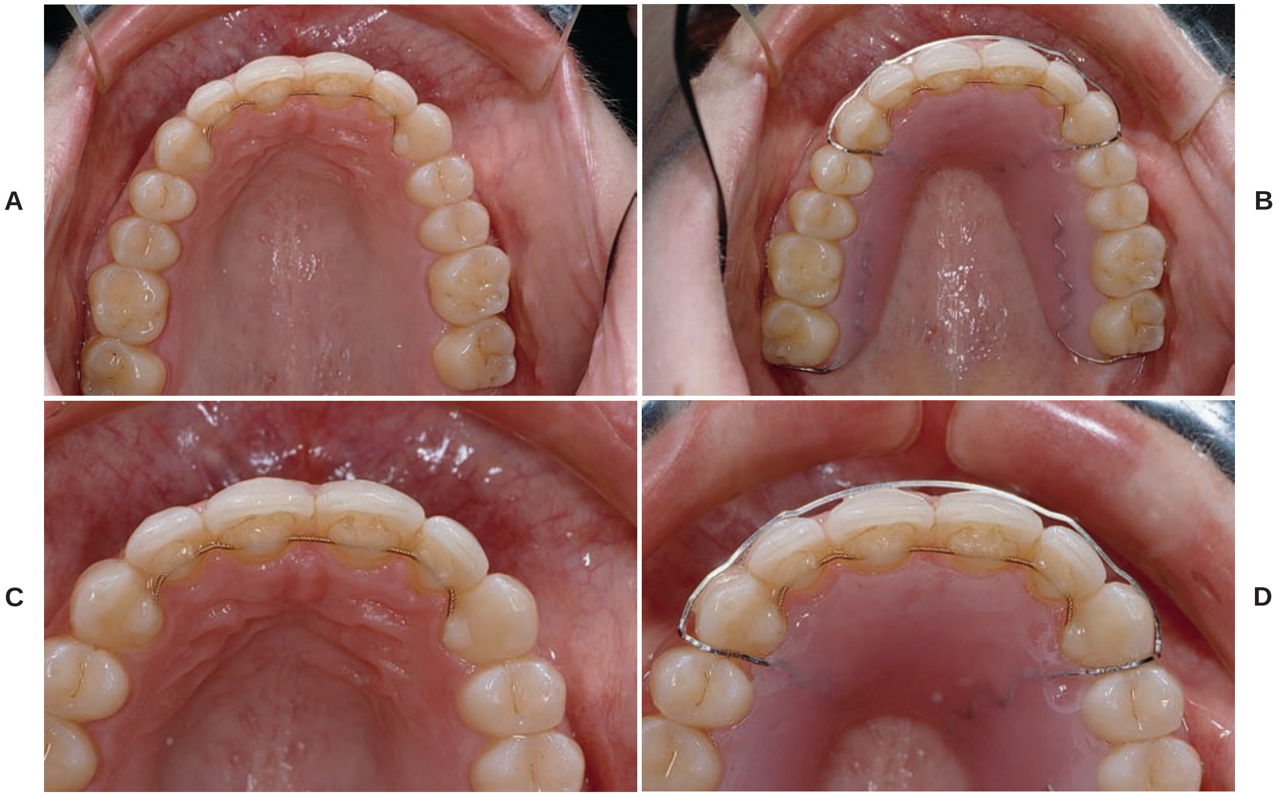

FIGURE 21-42 **A, C,** Recommended version of removable plate to be used with a six-unit bonded lingual retainer. The labial wire of this plate extends distal to the bonded retainer to avoid the risk of retainer wire fracture. The acrylic of the plate can be ground away from the teeth involved in the bonded retainer **(B, D).**

Because the failure rates increase significantly when the canines (and first premolars) are included in a maxillary FSW retainer, use of a four-unit design combined with a removable plate (see Figures 21-38 and 21-39) rather than a six-unit bonded retainer (Figure 21-43; see also Figure 21-42) is safer for routine retention in children and adults.

The mandibular 3-3 bar and 321-123 retainer show excellent and similar success rates.[46] The 3-3 bar is a safe retainer, and this design may be recommended for most children. For adults and adolescent patients with pretreatment spacings and similar malocclusions, the bonding of all six anterior teeth may be preferable.

Direct-Bonded Labial Retainers

Clinical experimentation with short labial retainers was started in the late 1980s to try to improve the long-term results in some specific retention situations. Typical problems were the following:

1. Inability to prevent some space reopening in closed extraction sites in adults
2. A tendency for some lingual relapse of previously palatally impacted canines
3. Space reopening when molars and premolars had been moved mesially in cases with excess space

Common to these situations was that some support in the premolar area for 1 to 2 years appears advantageous to improve stability. The background for bonding retainer wires labially was based on unsatisfactory results when the orthodontist bonded wires to the lingual surface of premolars. The alternative—bonding the wire occlusally in the premolars—presents other problems. In most instances, antagonistic contact cannot be avoided unless a groove is prepared, which is probably not acceptable in routine situations. It was decided therefore to bond short retainer wires labially to examine success rates and patient reactions.

Technical Procedure. In principle the fabrication of labial retainers is similar to the technique used for direct bonding of lingual retainers.

1. A straight piece of 0.0215-inch Penta-One wire (gold-coated or stainless steel) is cut to the desired length.
2. After etching, the retainer wire is tacked on the teeth.
3. After the adhesive sets, a bulk of adhesive is added.
4. Contour trimming of excess is done with tungsten carbide burs (No. 7408 and No. 7006), and interdental trimming is done with small round burs (No. 1 or No. 2). Care is taken to avoid contact between composite and gingival margin at the bonding sites, as well as contact between the interdental papillae and the retainer wire.

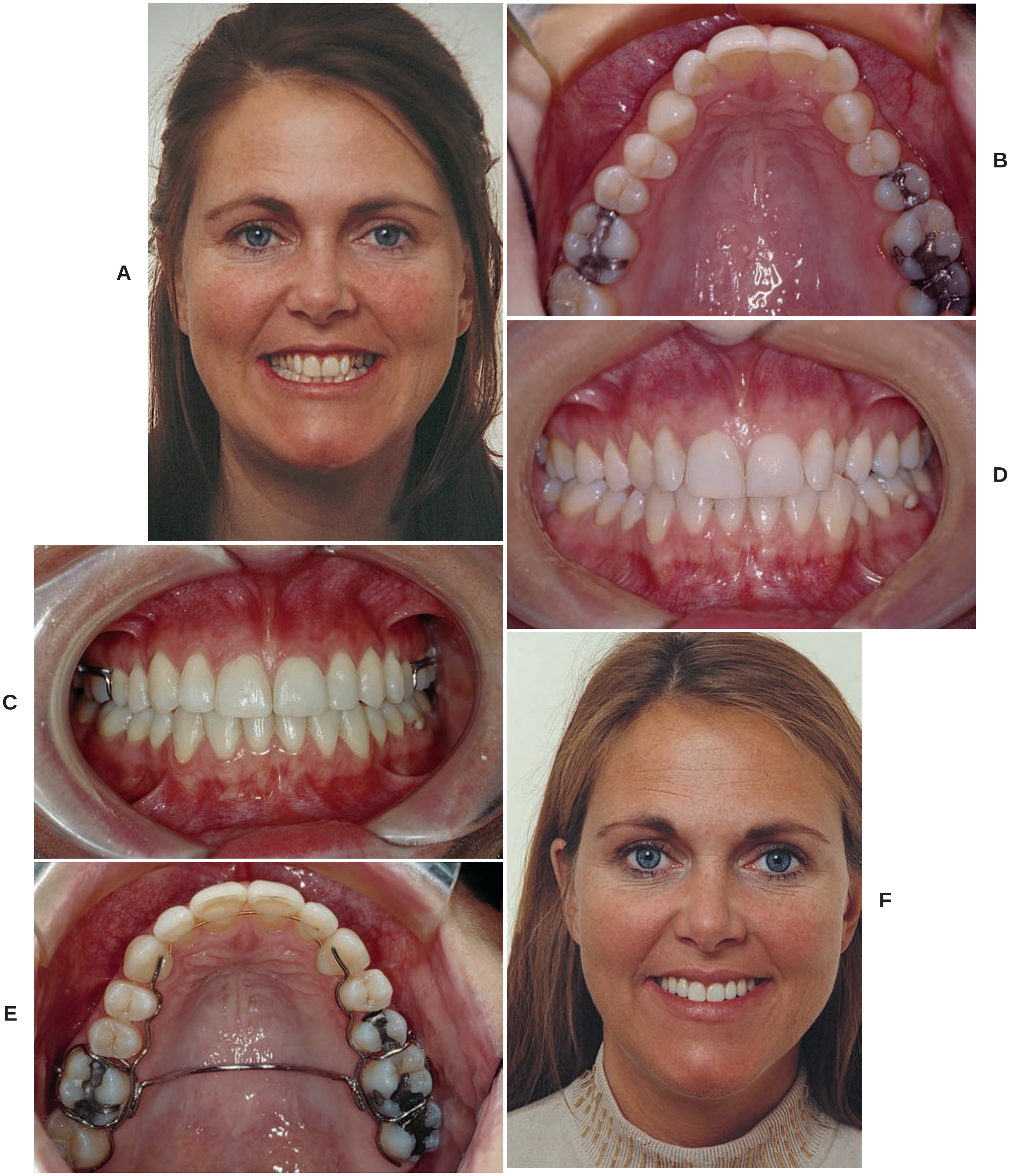

FIGURE 21-43 Combination of six-unit bonded lingual retainer and simplified Crozat appliance for retention in adult female patient with an anteriorly constricted maxillary dental arch and rotated and blocked out lateral incisors and canines **(A–C). E,** The Crozat is optimal for long-term retention of crossbites in adults. If the appliance is not worn for some time and slight transverse relapse occurs, its flexibility allows for recovery (similar to a spring retainer), in contrast to what is possible with a conventional removable plate. Note improvement of smile fullness **(F)** compared with the start **(A).**

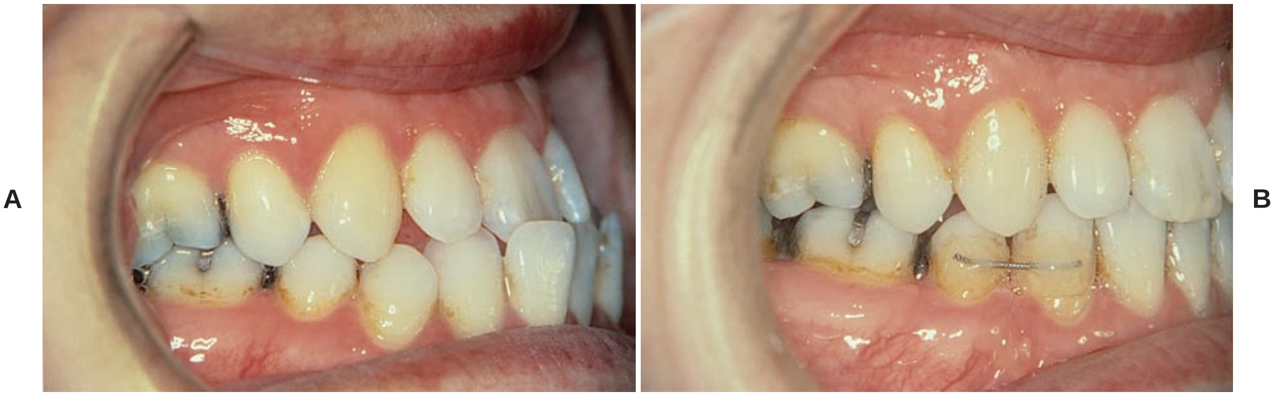

FIGURE 21-44 **A,** Adult male patient with Class III malocclusion. **B,** Short labial retainer after extraction of mandibular first premolars.

Long-term Results. The first follow-up study of direct-bonded labial retainers as reported by Axelsson and Zachrisson[52] demonstrated excellent results for short segments (two teeth) regarding bond success rate and, surprisingly, for patient acceptance. A gold-coated labial wire (Figures 21-44 and 21-45) is understandably more acceptable than a steel wire, even if some of the plating may wear off over time. The failure rates for retainers of two teeth were about 4% over an average period of 2 years. The retainers were placed over closed extraction sites in adults (Figure 21-44 to 21-46) or for added retention of previously palatally impacted canines (see Figure 21-32, *H*).

When longer retainers (three to four teeth) were placed labially in the mandible, however, the bond failures increased significantly.[52]

OTHER APPLICATIONS OF BONDING

Numerous other clinical possibilities of interest to orthodontists exist in which the acid-etch technique and bonding has proved useful:

- Space maintainers
- Semipermanent single-tooth replacements
- Trauma fixation
- Resin buildups for tooth size and shape problems

Bonded Space Maintainers

Several approaches to bonded space maintainers have been described, with varying degrees of short-term success reported. Long-term results on a group of patients are not available for any design. Figures 21-47 and 21-48 show recent designs of bonded space maintainers made from plain, round 0.032-inch stainless steel wire sandblasted terminally for micromechanical retention or from gold-coated 0.030-inch wire.

More studies may be needed on specific designs of bonded space maintainers on the labial or lingual aspects before a variant for routine use can be accepted universally.

Bonded Single-Tooth Replacements

Because of the well-known problems with fixed bridgework and removable appliances of the spoon denture type in young patients, acid etching and bonding offer a range of aesthetic techniques for the solution of the problem with anterior teeth. The use of resin-bonded bridgework (three-unit or cantilever) has become accepted as a semipermanent procedure. Failure rates over a 10-year period may be in the 30% range, particularly if cases are selected to allow no or only limited occlusal contact on the restoration. Higher failure rates have been experienced with the presence of occlusal contact, particularly in children.

A cheaper, simpler, and perhaps more durable alternative than the cast variants for anterior tooth replacement is shown in Figure 21-49.

The procedure aimed at the following properties:

1. Possibility for physiologic movement of the bridge units within the periodontal tissues
2. Avoidance of direct occlusal contact on metal
3. Avoidance of metal shine through
4. Uncomplicated repair
5. Access to the pulp cavity and root canal in cases where endodontic treatment might be indicated. Of particular interest is the fact that similar types of replacement can be used during orthodontic treatment. Porcelain or acrylic teeth can be attached to neighbors to avoid empty-looking spaces in adults when premolar or incisor extractions are needed and for absent maxillary lateral incisors while waiting for a more optimal time for implant insertion.

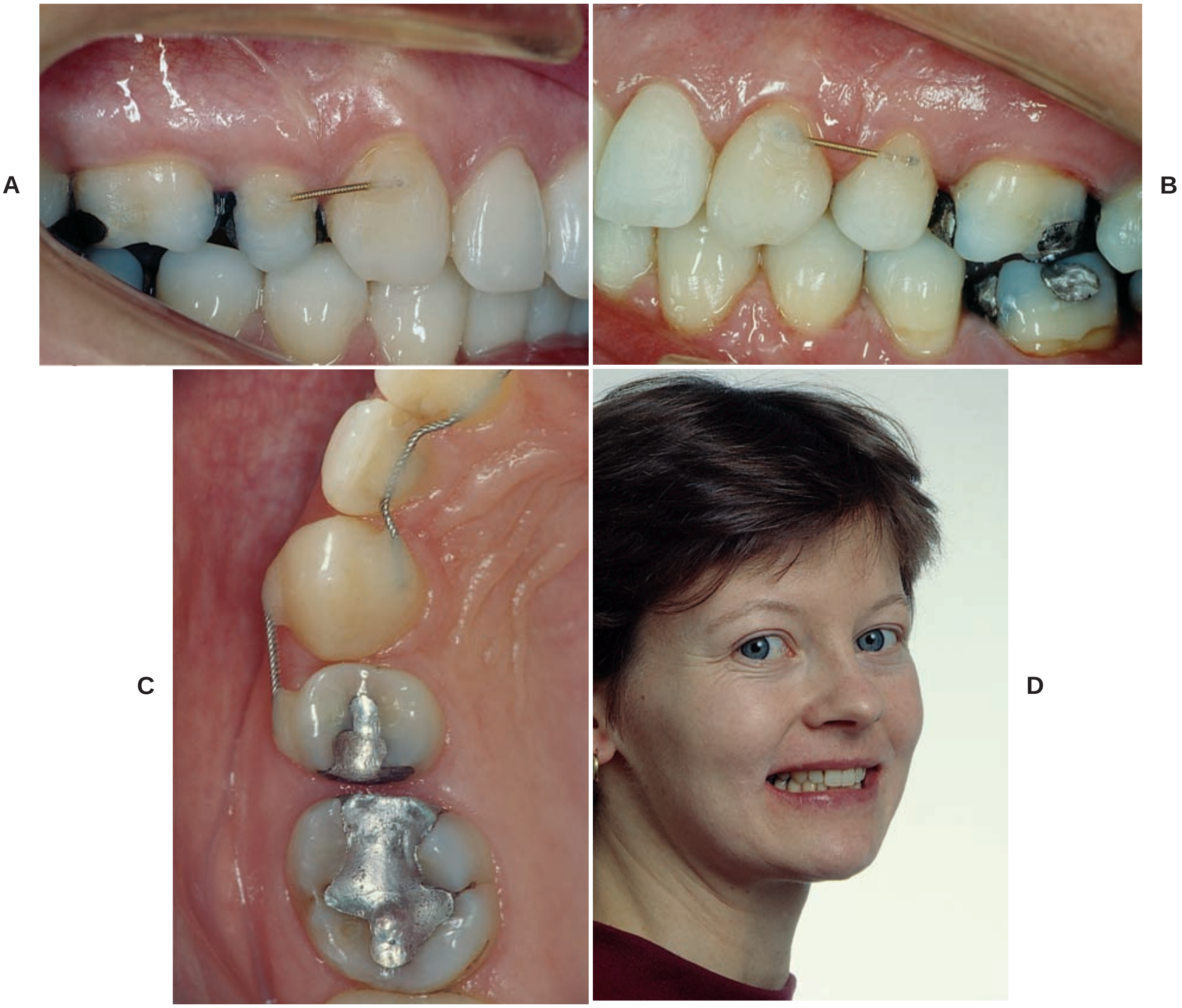

FIGURE 21-45 Slight space reopening distal to a short labial retainer in an adult woman requiring upper first premolar extraction. **A, B,** Gold-coated labial retainers. **C,** The reopening evidently reflects a tooth size discrepancy that can be addressed when remaking the amalgam fillings. **D,** The labial wire is inconspicuous on smiling.

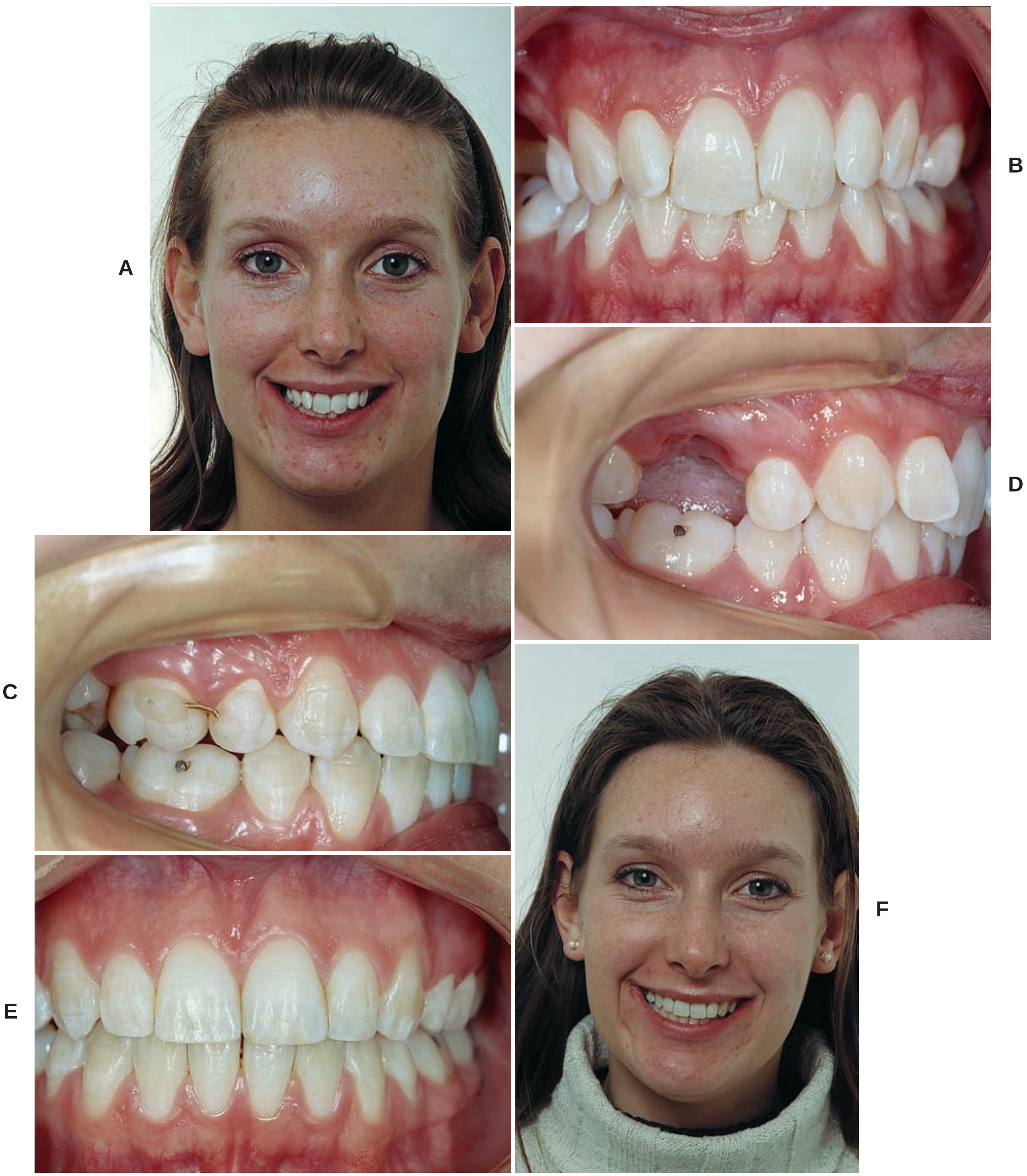

FIGURE 21-46 **A–C,** Young adult female patient with typical Class II, Division 2 malocclusion before treatment. The maxillary first molar was extracted as part of treatment **(C).** The second molar and first premolar were held together with a short gold-coated labial retainer. The maxillary third molar is erupting. **D–F,** Note the improved maxillary canine occlusion and incisor torque.

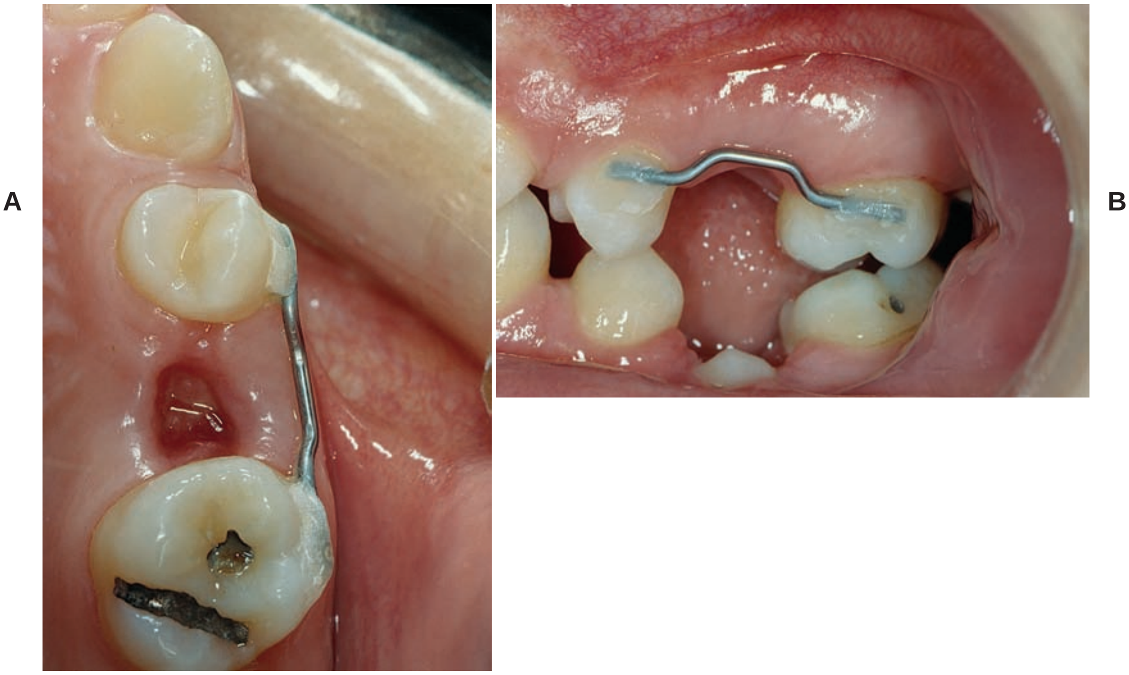

FIGURE 21-47 Recommended design for bonded space maintainers using round 0.032-inch stainless steel wire sandblasted on the terminal ends for micromechanical retentions **(A, B)** or using six-stranded 0.032-inch spiral wire with utility wire design.

Splinting of Traumatic Injuries

The goal of splinting traumatized teeth is to stabilize, allow healing, and prevent further damage to the pulp and periodontal structures. Several types of traumatic splinting devices are used conventionally, but for various reasons none of these splints is optimal. Thus clinical experiments using different bonded wires are interesting. Short-term studies have demonstrated clinical success with bonded plastic wire and stainless steel spiral wire. Such splints allow physiologic mobility of the splinted teeth, which has been found to be preferable to rigid splinting (except possibly for root fractures).

Composite Buildups and Porcelain Laminate Veneers

The addition of composite resin or porcelain laminates to noncarious teeth during or after orthodontic treatment may be indicated on single or multiple teeth to solve tooth shape and size problems. A range of situations exist in which buildup techniques may provide aesthetic improvement of the orthodontic result.

For example, small or peg-shaped maxillary lateral incisors (Figure 21-50) and canines brought into contact with maxillary centrals when the laterals are congenitally missing (Figure 21-51) may need such aesthetic improvement. Occasionally, autotransplanted first premolars in maxillary incisor position[61] also need reshaping with resin.

More demanding situations require porcelain laminate veneers or veneer crowns, including cases in which premolars have been autotransplanted to the maxillary anterior region.[61] The aesthetic result that may be obtained with one or several porcelain veneers bonded to prepared transplanted premolars is outstanding. The combined surgical–orthodontic–prosthetic interdisciplinary effort is an excellent way to solve difficult treatment problems associated with traumatic injuries of the teeth in young patients.

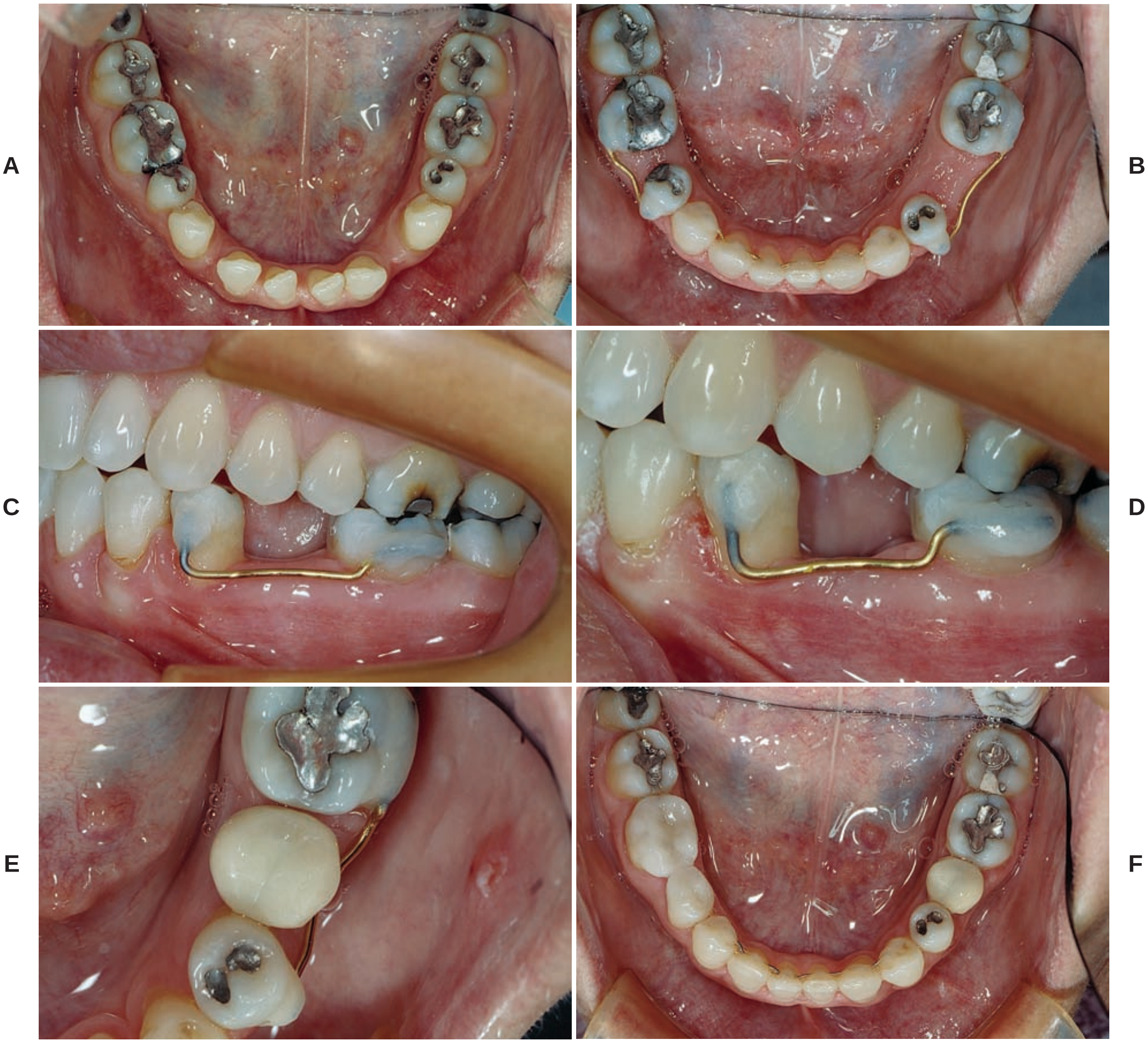

FIGURE 21-48 **A,** Adult woman with agenesis of two mandibular incisors and thin periodontal tissues. **B–D,** Gold-coated space maintainer. The mandibular left first and second premolars were moved one tooth width mesially **(B)** to regenerate improved alveolar bone thickness to accommodate a single implant **(E, F).**

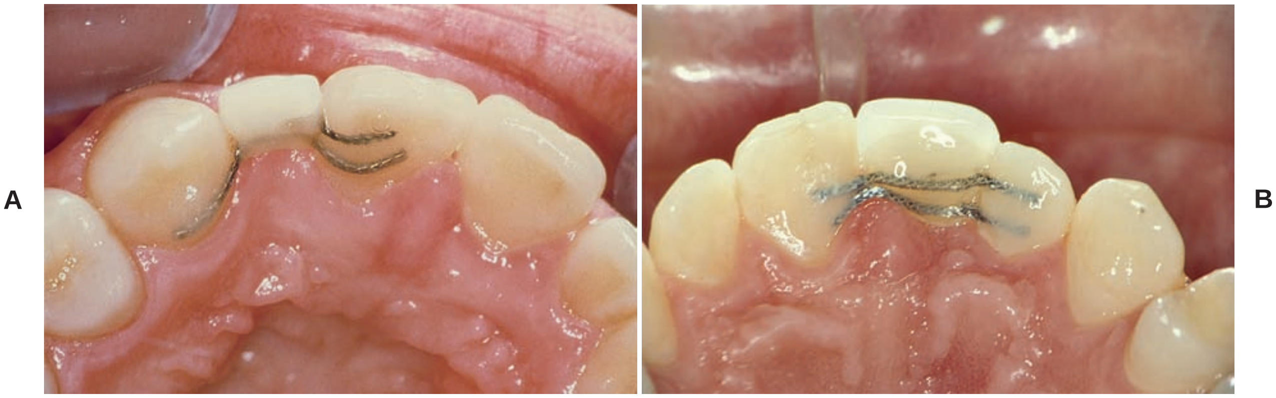

FIGURE 21-49 Three-wire design for single tooth replacement of a missing right lateral incisor **(A)** and four-wire version of the resin-bonded bridge, where the two braided wires run continuously through the pontic **(B).** Note the attempts to achieve clean interdental conditions.

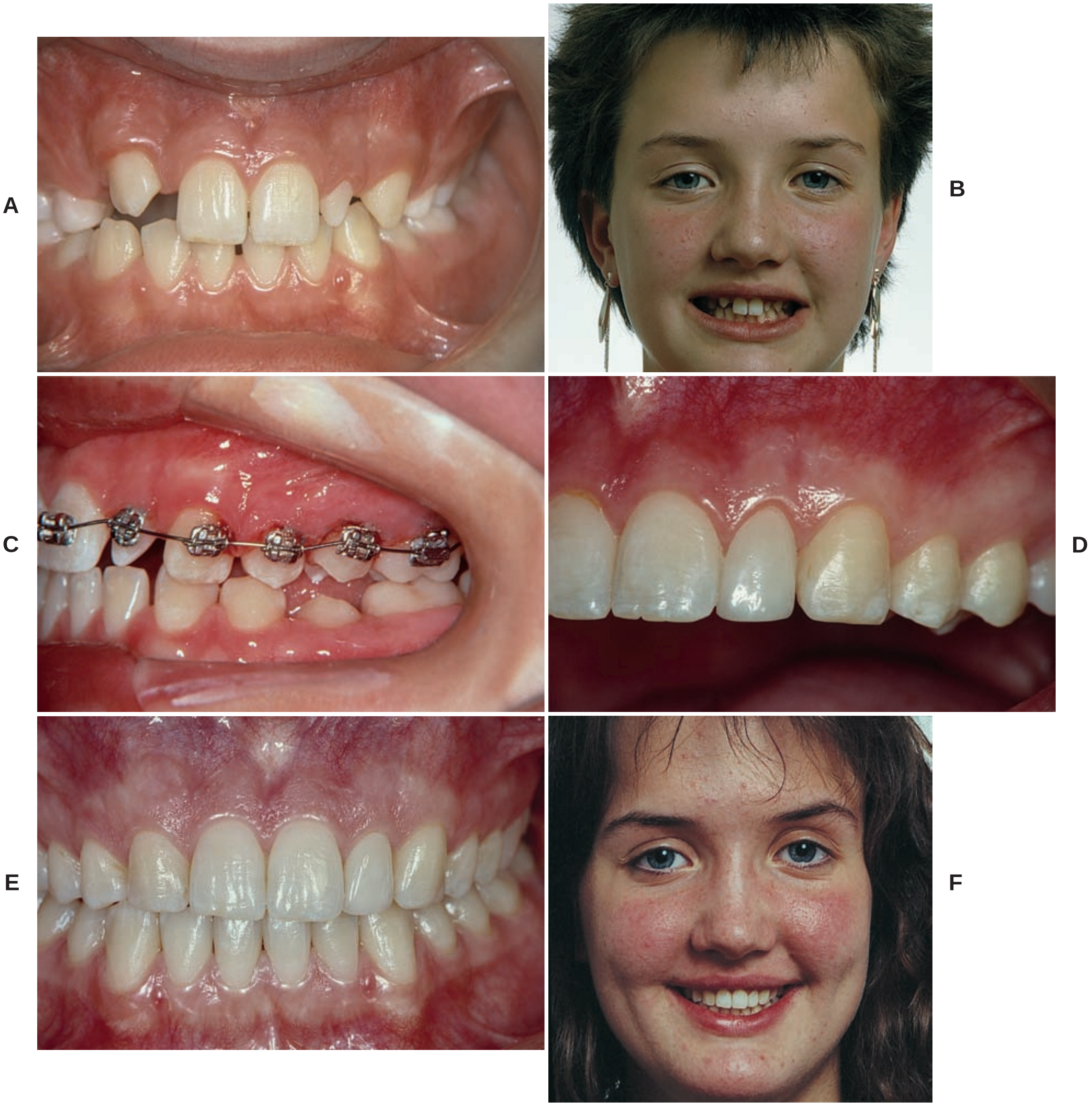

FIGURE 21-50 **A, B,** Young female patient with agenesis of maxillary right lateral incisor and peg-shaped left maxillary lateral incisor. Clinical result of orthodontic space closure **(C)** was modified by recontouring the canine to the lateral incisor shape by grinding and making a porcelain laminate veneer on the peg lateral **(D, E). E, F,** Final result.

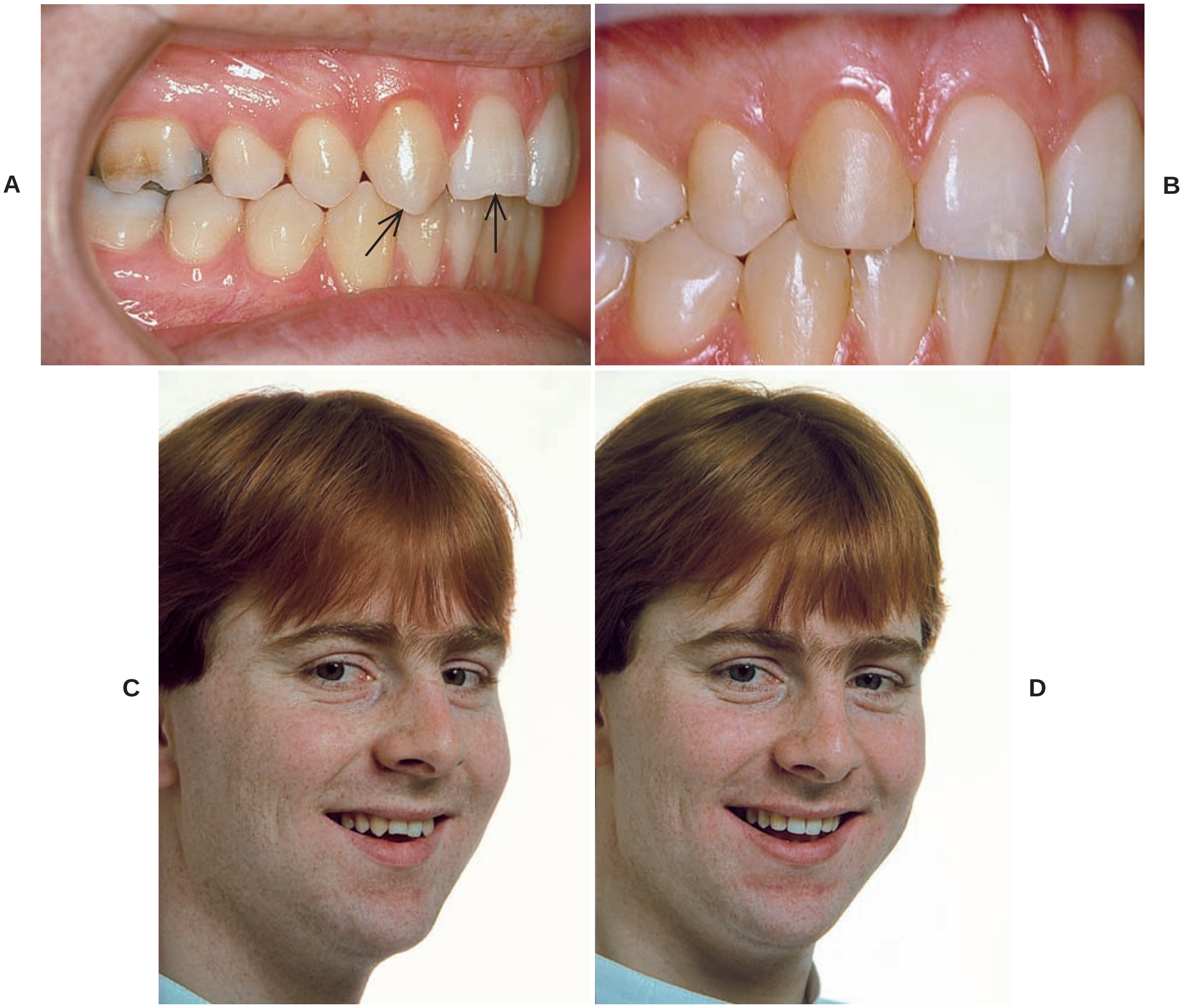

FIGURE 21-51 Composite buildup leading to aesthetic improvement postorthodontically for a patient in whom the maxillary lateral incisors were missing. **A,** After space closure. Note the unfavorable appearance of both canines and the traumatically injured right central incisor (*arrows*). **B,** Combination grinding of the canines and composite buildup on the mesial aspects of the canines and the incisal edge of the central incisor. **C, D,** Results of this quick procedure.

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CHAPTER 22

Nonextraction Treatment

Norman M. Cetlin, Raffaele Spena, Robert L. Vanarsdall, Jr.

> *In Orthodontics as in every other science, each period reveals truths and steps in progress which prove the former theories and practices to have been wrong; so it behooves us not to be too dogmatic in our statements for we are dealing with the unknown, so at the best our concepts must be largely hypothetical.*
>
> ***John V. Mershon***

OUTLINE

Treatment Planning and Sequence
The Original Cetlin Approach
  Phase Sequences
Phase I: Space-Gaining Phase
  Upper Arch
    Palatal Bar
    Extraoral Force
    Clinical Management of Headgear
    The Removable Distalizing Plate
    Clinical Management of the Distalizing Plate
  Lower Arch
    Lip Bumper
    Class III Mechanics
Evolution of the Technique
Comparison of Two Distalization Methods: Pendulum versus Palatal Bar Plus Pendulum
Molar Uprighting and Vertical Control after Distalization with the Pendulum
Segmental Alveolar Corticotomy to Enhance Upper Molar Distalization
  Space Utilization
Conclusions

The decision of whether or not to extract permanent teeth in planning the treatment of an orthodontic case is a crucial moment for the clinician, especially when facing a borderline case. The education, experience, and skill of the clinician on one side and the requests or the limitations imposed by the patient on the other side may greatly influence the final solution and, eventually, the outcome.

Extractionists and nonextractionists still debate the best way of treating an orthodontic malocclusion with crowding, but clinical research has thus far failed to demonstrate that nonextraction treatment is better than extraction treatment (or vice versa). No difference in influencing the final dental and facial aesthetic result, no difference as far as the final functional result, and no difference in final stability has been established, because of the great variability and unpredictability from patient to patient. Dogmas have been proposed, but most have proved to be inadequate.

The nonextraction approach proposed by Norman Cetlin has long been used by several clinicians with excellent clinical results. In the past few years, some modifications have been proposed in order to overcome the problems related to the headgear appliance and the distalizing plate, trying to reduce the level of patient compliance required.

New procedures and techniques have been adopted to improve control of the dental anchorage and movement: mini-implants to ensure skeletal anchorage, segmental (e.g., limited to a tooth or a group of teeth) corticotomy to facilitate dental movement, self-ligating brackets with thermal NiTi wires trying to reduce the level of applied force and friction produced.

This chapter presents a nonextraction approach that is divided into two phases: (1) an initial space-gaining phase and (2) a final space-utilization phase. Sagittal and transverse corrections and major tooth movements are accomplished in the first phase, while full bracketing and final detailing are achieved in the second phase. In the final section, modifications of the technique with the adoption of new appliances and methods are presented.

TREATMENT PLANNING AND SEQUENCE

The objectives of the first, or space-gaining, phase are to increase space and change the original malocclusion into a "super Class I" malocclusion with ample spaces in

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both upper and lower arches. Molar rotation, inclination, and crossbite are corrected, and the curve of Spee is leveled. In the second, or space-utilization, phase, Andrews' six keys to normal occlusion[1] are obtained, with some modifications as described. Overbite, overjet, and all dental malpositions are corrected. Spaces are closed and a good anchorage is established during the entire treatment period. The final objective is a mutually protected occlusion with canine and incisal guidance.

This approach is most suitable for treating Class I and II malocclusions with upper and lower crowding. The best patients are those who are growing and who are in the late mixed dentition stage (i.e., right before the exfoliation of second deciduous molars). This stage offers several advantages:

- The leeway or "E" space is still available.
- Facial growth is at its peak.
- Tissues respond better to mechanical deformation and remodel more quickly.
- Since good cooperation is an essential factor, more can be obtained before the patient becomes socially and academically active.

With proper timing, treatment can be completed in 18 to 30 months, depending on how rapidly teeth erupt and skeletal changes occur. It should be noted that the procedures presented in this system are viable and acceptable for both children and adults. A lesser and slower response generally is expected in adults, but the final result can be equally satisfactory.

THE ORIGINAL CETLIN APPROACH

In its original version, the appliances employed in this approach were used to gain space and, in a growing patient, allow growth to reach its potential.

Class I and Class II molar relationships may be found in a great variety of sagittal, transverse, and vertical dental and skeletal combinations. The most frequent skeletal situation is a pattern with fairly normal vertical proportions, normally positioned maxilla, and different levels of retruded mandible. This is what McNamara has found in his Class II population.

Gaining space in the upper and lower arch is the key phase of any nonextraction treatment, since crowding is very often found. The objectives of this initial part are (1) correction of molar inclination, rotation, and crossbite; (2) overcorrection of molar relationship; and (3) generalized spacing in both the upper and lower arch.

Space may be gained in the arch in several modalities. If we exclude surgical modalities (e.g., distraction osteogenesis, surgical assisted maxillary expansion) that have specific and limited indications, there are 10 ways to create space in an arch:

1. Distolateral rotation of mesially rotated and constricted upper molars (found in most of Class I and II malocclusions with crowding)
2. Distalization of upper molars (in both Class I and II malocclusions)
3. Distal and buccal uprighting of lower molars (as leveling of the curve of Spee occurs)
4. Distal rotation of ovoid premolars
5. Maintenance of the leeway space
6. Modification of the arch width (orthopedic/orthodontic transverse increase in the maxilla; orthodontic transverse increase in the mandible)
7. Modification of the archform (an initial constricted, tapered archform needs to be changed in the same way a rotated tooth needs to be corrected)
8. Selective stripping on trapezoid teeth or teeth with interproximal fillings or teeth with abnormal anatomy. In these cases, the Bolton ratio must be carefully evaluated.
9. Incisor repositioning (depending on periodontal, aesthetic, skeletal, and dental features of the patient)
10. Extraction of teeth (the last option)

Phase Sequences

The most commonly used treatment sequence in the space-gaining phase is as follows:

- Upper arch
  - Crossbite correction, as well as rotation, distalization, and torque of upper molars with one or more palatal bars
  - Molar distalization
  - Creation of a super Class I molar relationship
  - Molar anchorage to allow spontaneous distal drift of premolars and canines
- Lower arch
  - Insertion of a lip bumper on the first or second lower molars
  - Achievement of an upright and rotated position of lower molars
  - Constant reactivation of lip bumper to permit spontaneous lateral dentoalveolar growth and leveling of curve of Spee
  - Use of Class III elastics from overcorrected upper molars to canine hooks on lip bumper to enhance uprighting force on lower molars

The most commonly used treatment sequence in the space-utilization phase is as follows:

- Upper arch
  - Creation of a posterior anchorage unit
  - Leveling and alignment of the upper arch
  - Closure of residual spaces
  - Detailing of the arch and occlusion

- Lower arch
    - Correction of rotations and dental malpositions
    - Complete leveling of curve of Spee
    - Closure of residual spaces
    - Detailing of the arch and occlusion

PHASE I: SPACE-GAINING PHASE

Upper Arch

Space was gained in the upper arch through the use of three appliances: the palatal bar, the headgear, and the removable distalizing plate. The palatal bar (PB) helped to correct maxillary constriction, rotation, distalization, and torque of both first and second upper molars; it also controlled them vertically. The extraoral forces (cervical or occipital, depending on the skeletal pattern) were used to control the roots and the vertical dimension of the upper molars.[2] The removable Cetlin plate, with two distalizing springs against the first molars, tipped the crowns distally while maintaining a good control of anterior anchorage. The combined actions of extraoral force and the plate created a two-force system that allowed bodily distal movement of the upper molars.

Space was gained in the sagittal dimension as well as in the transverse dimension. Premolars and canines followed molars in a more distal and lateral position. The entire upper arch widened and spontaneously changed its form. The overjet often decreased because the upper front teeth tipped lingually in a better position and/or the mandible, released from a constricted upper arch, repositioned and grew forward.

The objectives of the space-gaining phase were to drive molars into a "super Class I" relationship and to create diastemas all around in order to correct overjet and overbite and obtain a good canine relationship.

Palatal Bar. The PB was introduced by R. H. Goshgarian as an anchorage appliance. Cetlin and TenHoeve[3] have modified it to make it a removable tooth-moving appliance. The PB is made of a 0.036-inch stainless steel (spring temper) wire, doubled back at the ends to be inserted in a 0.036- × 0.072-inch horizontal lingual sheath (Figure 22-1, *A*), which is soldered to molar bands (Figure 22-1, *B*). These lingual sheaths (Figure 22-1, *C*) have an 8-degree mesial offset that facilitates insertion and removal of the PB, preventing blocking behind premolars after molar rotation. A distal latching indent and a gingival hook help to tie back the PB and aid in insertion of intra-arch or interarch elastics (Figure

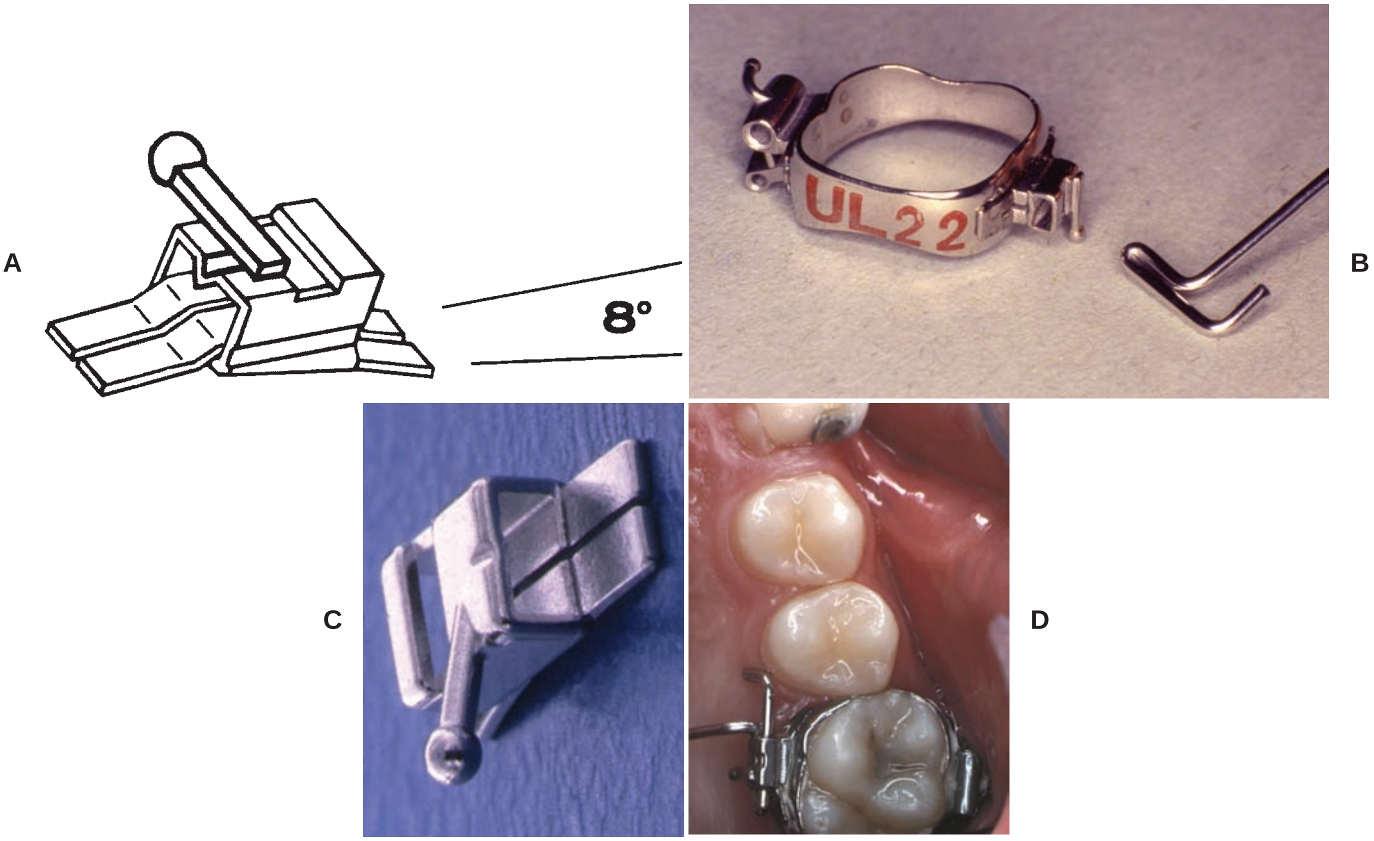

FIGURE 22-1 **A,** A lingual sheath holds the palatal bar (8-degree medial offset). **B,** The lingual sheath is welded to the maxillary first molar band; a gingival hook is used. **C,** A close-up distal view of the lingual sheath. **D,** A maxillary left molar with a palatal bar held in place with an elastic attached to gingival hooks.

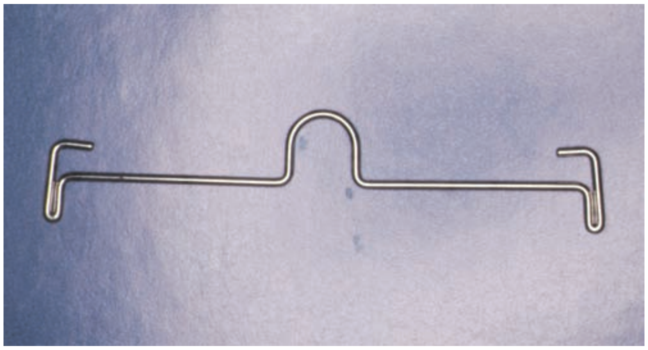

FIGURE 22-2 A transpalatal bar with a U-loop positioned generally toward the mesial.

22-1, *D*). The PB incorporates a small "U-shaped" Coffin loop (Figure 22-2), which is positioned generally toward the mesial for two reasons: (1) to make the PB more comfortable and (2) to incline molar roots distally because of forces exerted by tongue during speech and swallowing anterior to the center of resistance (CR) of molars.

The loop is left distal if intrusive force is desired posterior to the center of resistance to tip molar crowns distally. It must be remembered, however, that direction of the loop gives these different effects on upper molar inclination only when the PB is distant from the palate and low in oral cavity.

Fitting of a Palatal Bar. The initial objectives in fitting the PB are to obtain one that is well shaped to the palate, does not impinge on soft tissues, and exerts forces only on the molars where it is inserted. Because working with the PB in patient's mouth is uncomfortable, it is advisable to get as close as possible to a well-fitted passive PB on the initial casts before starting to insert it in the molar lingual tubes.

Once the PB has been well fitted, the passive form should be checked in the patient's mouth and recorded on the patient's chart as a reference mark. A PB is passive when one terminal has been inserted and the other end lies at the same transverse level with the same rotation, inclination, and torque to its sheath.

Clinical Use of the PB. The PB is used on both first and second permanent molars. Because working in the back of the mouth is uncomfortable for the patient and the orthodontist, at least two means to hold the PB should be used when inserting and removing it. A hemostat, with a dental floss tied around it, can be useful to hold safely the PB while seating the terminals in their sheaths with a Weingart pliers (or better, a Dentronix 260 pliers). Second molars should be banded and moved with the PB as soon as possible to facilitate distal movement of the first molars.

Forces applied with a PB must be light and in one direction. For example, rotation and torque should not be attempted at the same time. Overactivation leads to soreness, mobility, destruction of the lamina dura, and periodontal breakdown and does not produce results more quickly. Reactivation is required approximately every 6 weeks. Terminals must always be checked to ensure that they are passive to their tubes before additional force is added.

PBs must be tied. This can be done with an elastic or chain from the hook of the sheath to the curved end of the bar. Ligatures prevent the PB from being dislodged or, worse, swallowed.

PBs can be used for the following purposes:

- Distalization
- Rotation
- Expansion or constriction
- Vertical control
- Torque
- Anchorage increase

Distalization. Distalization is the only unilateral activation of the PB. It can be used in two clinical situations: (1) when, in a malocclusion, there is a Class II molar relationship on one side and the other side is normal or (2) when both upper molars must be distalized and the patient does not want to wear headgear.

In the first situation, rotation on the Class I side is offset with a headgear with an inner bow that has a toe-out on this side or an edgewise wire extended at least to the controlateral premolar (Figures 22-3 to 22-8).

Rotation. L. F. Andrews[1] (see Chapter 14) has observed that molar relationships in untreated normal patients are defined by three contacts between the upper molars and lower molars: (1) The mesiobuccal cusp of upper first molars occludes with the mesiobuccal groove of lower first molars; (2) the distal marginal ridge of upper first molars contacts the mesial marginal ridge of lower second molars; and (3) the palatal cusp of upper first molars occludes with the central fossa of lower first molars. Most Class I and Class II malocclusions present mesiolingually rotated and constricted upper molars. When the upper first molars are rotated, several problems may occur:

1. The relationship between the upper first molars and the lower molars on the buccal side is different from that on the palatal side. Molar relationships always look worse in the buccal view. If the palatal cusps still seat in the central fossa, the faulty molar relationship is easier to correct; however, if occlusion occurs mesial to the central fossa, the Class II molar relationship is more difficult to solve.
2. The upper first molar distal surface faces buccally and second molars tend to erupt laterally.
3. If the upper molars are banded, archwires or headgears may be difficult to insert.

An upper first molar measures approximately 10 mm from mesial to distal. From its mesiobuccal corner to its

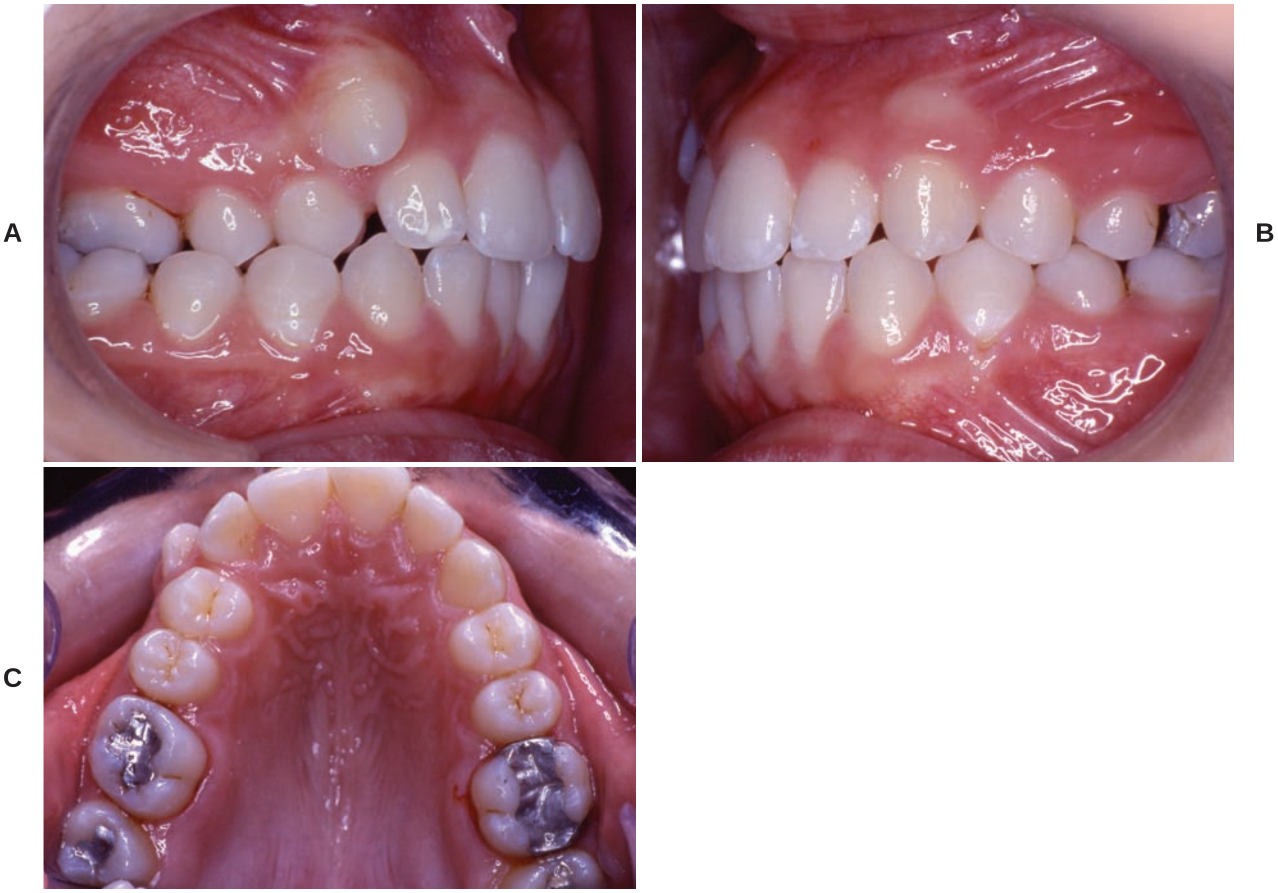

FIGURE 22-3 **A–C,** A malocclusion with Class II molar relationship on the right side and Class I molar relationship on the left side. A unilateral crossbite is present on the right side.

distopalatal corner, it measures 13 mm. For this reason, distal rotation of upper molars may gain as much as 3 mm of space per side. Furthermore, several false Class II relationships (i.e., those in which the palatal cusp of upper molar sits in the central fossa of lower molars) may be resolved simply by rotating the upper molars distally.

Upper second molars are usually triangular. Rotating these molars helps gaining additional space in the upper arch and facilitates distalization of the first molar. They therefore should be banded and moved as soon as possible. If needed, an extraoral force should be added on first molars as soon as it can be easily inserted.

As a final objective, upper first molars occupy a wider part of the arch, whereas upper second molars are more lingually placed. For this reason, the activation of the PB on the first molars is different from the activation on the second molars. Premolars usually follow molars laterally in a distal direction because of the transeptal fibers. It should take 3 to 4 months to rotate the upper molars completely.

Expansion or Constriction. The PB can solve transverse problems such as cross-bite and lateral overjet. These corrections should be made before rotating or distalizing the molars. Activation should be in the range of 1.0 to 1.5 mm of expansion or constriction per side and per activation until the problem has been corrected. Lateral movement of upper molars can be either coronal tipping or bodily movement. If bodily movement is required, buccal-root torque (when expanding) or lingual-root torque (when constricting) must be added.

To correct a unilateral crossbite, a vertical elastic (to maintain occlusion on the normal side) and a cross elastic (to increase lateral movement of the abnormal side) are added to the expanded PB (Figure 22-9). Premolars usually follow upper molars in the lateral movement, thus spontaneously correcting their position. In young patients, expansion with a PB may cause the palatal suture to open.

Vertical Control: Intrusion. Vertical control of upper molars is a peculiar aspect of this nonextraction mechanics. Most nonextraction approaches deal nicely with molar distalization but afford little or no vertical and transverse control. Control is needed in almost any case, but it is mandatory if nonextraction treatment is to be used in cases with dental or skeletal openbite tendency.

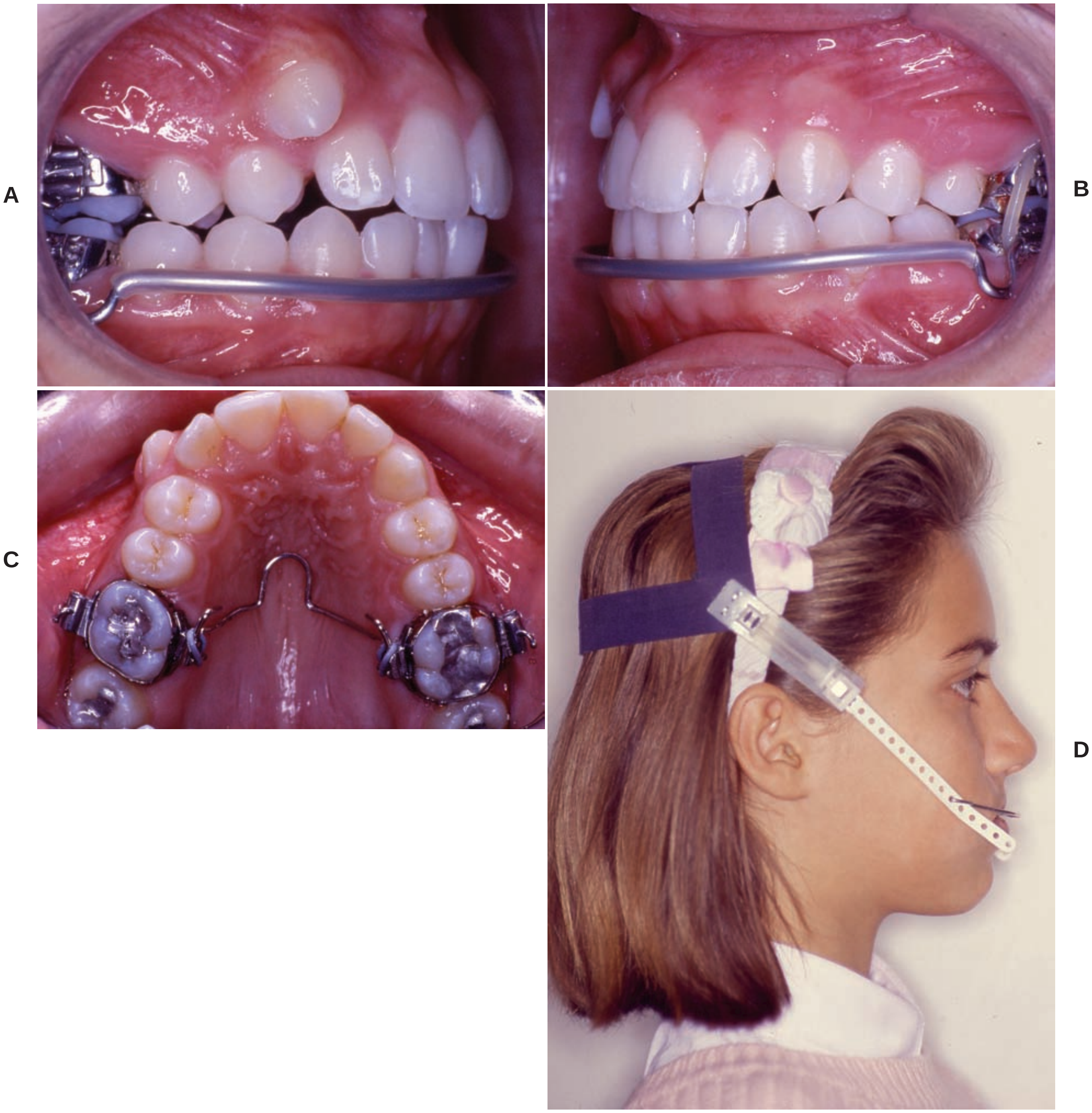

FIGURE 22-4 **A–D,** An expanded palatal bar with distal force on the right side is inserted. The lateral force is offset on the left side with a vertical elastic, and the rotational force is offset on the left side with the extraoral force.

The PB, alone or with a high-pull headgear, can be used to take advantage of the intrusive force exerted by the tongue during chewing, swallowing, and speech. The PB is kept low in the oral cavity, 4 or 5 mm away from the palatal vault. To increase the surface on which the tongue will be acting, two extra loops (Figure 22-10) or an acrylic button can be added to the Coffin loop; this makes the PB more comfortable and effective.

By controlling molar eruption, or even more by intruding the molars, the orthodontist can correct or prevent vertical problems, obtain an upward and forward rotation of the mandible and correct sagittal problems. In mixed dentition, the effect can be enhanced by grinding the occlusal of the primary molars (Figure 22-11) as the upper permanent molars are kept away from the occlusion.

In a study conducted at the University of Ferrara, 13 male and 12 female patients, with an average age of 7.3 years (range, 6.7 to 8.5 years), with an anterior openbite due to various causes (i.e., thumb sucking, oral breathing, tongue thrust, and so on) and a skeletal divergence, were treated with a low PB, a high-pull headgear and

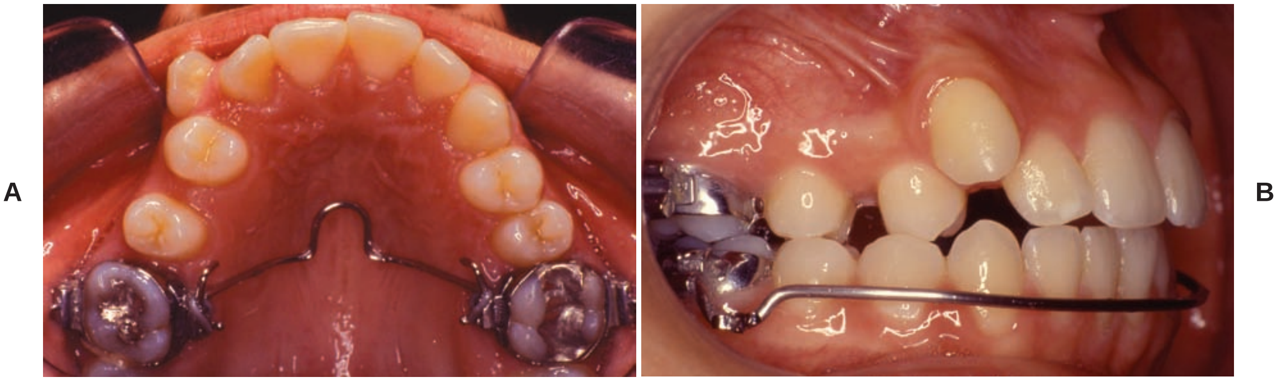

FIGURE 22-5 **A,** After a few activations, the upper right molar has been distalized and moved laterally to correct the Class II relationship and the crossbite. **B,** In the second situation, the palatal bar is activated first on one side and then on the other to obtain as much distalization as possible without the use of headgear or distalizing plate (see Figures 22-7, 22-8, and 22-9).

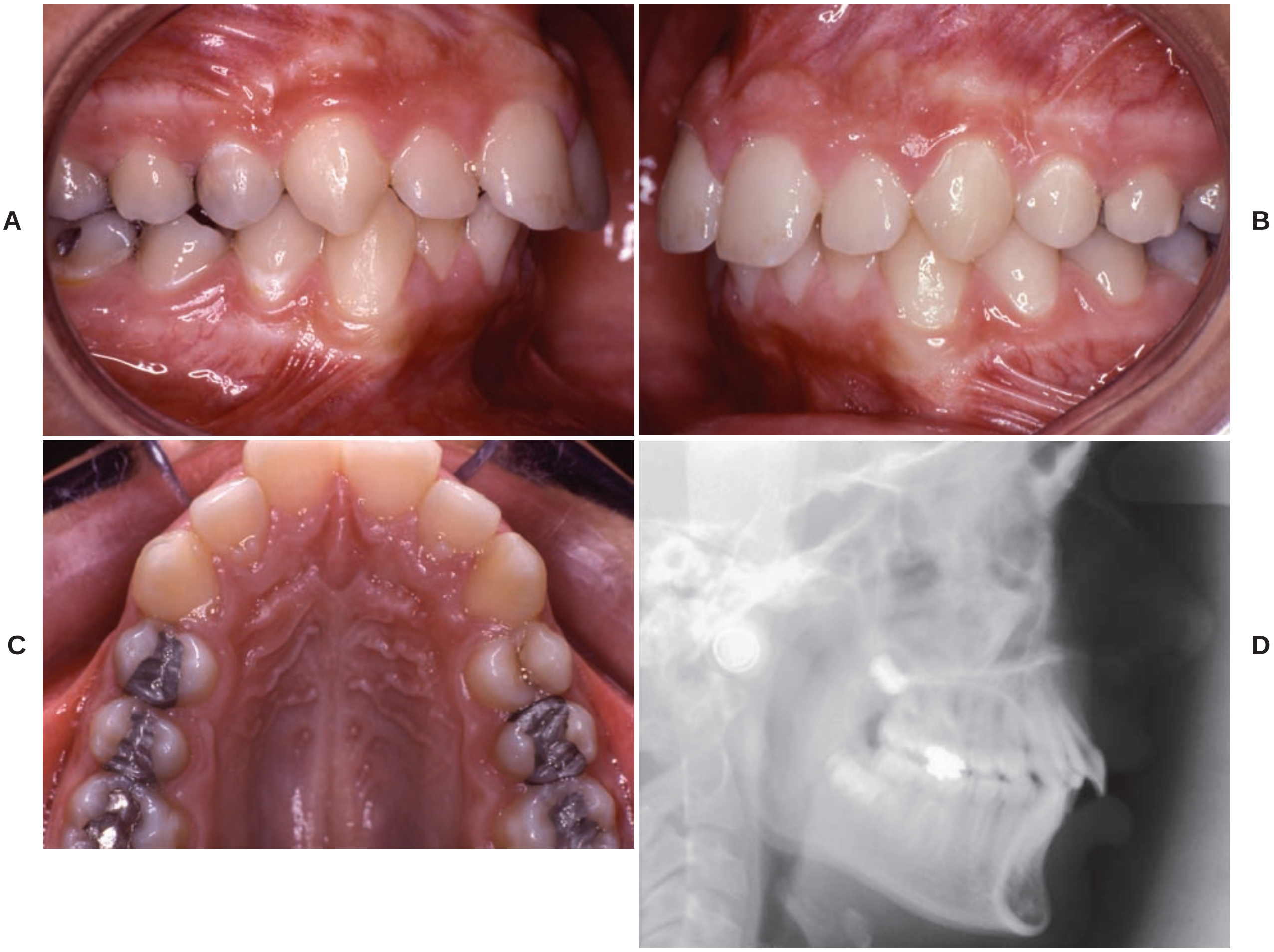

FIGURE 22-6 **A–C,** A malocclusion with Class I molar relationship, bimaxillary protrusion and crowding, and increased overjet and overbite **(D).**

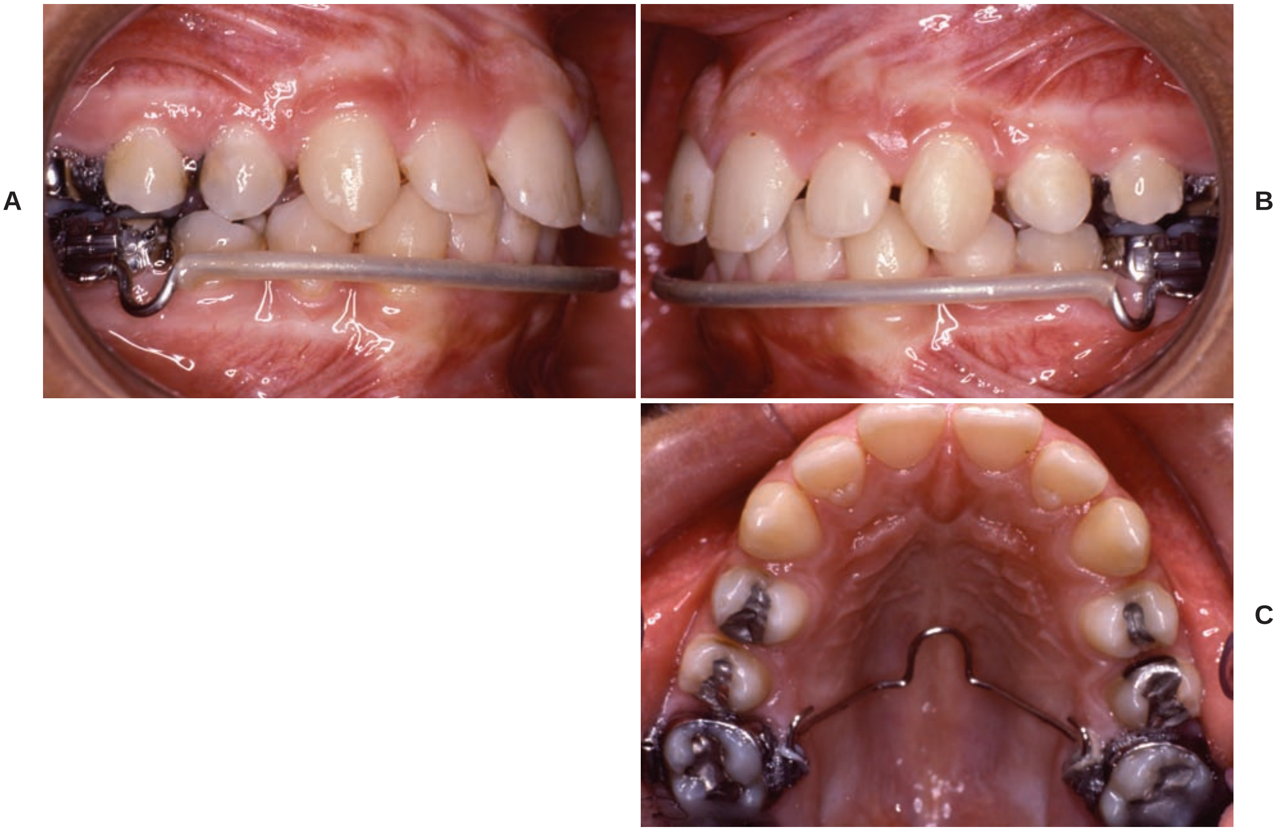

FIGURE 22-7 **A–C,** A palatal bar with distal force first on one side and then on the other has been used. Note the changes in the sagittal as well as in the transverse dimension.

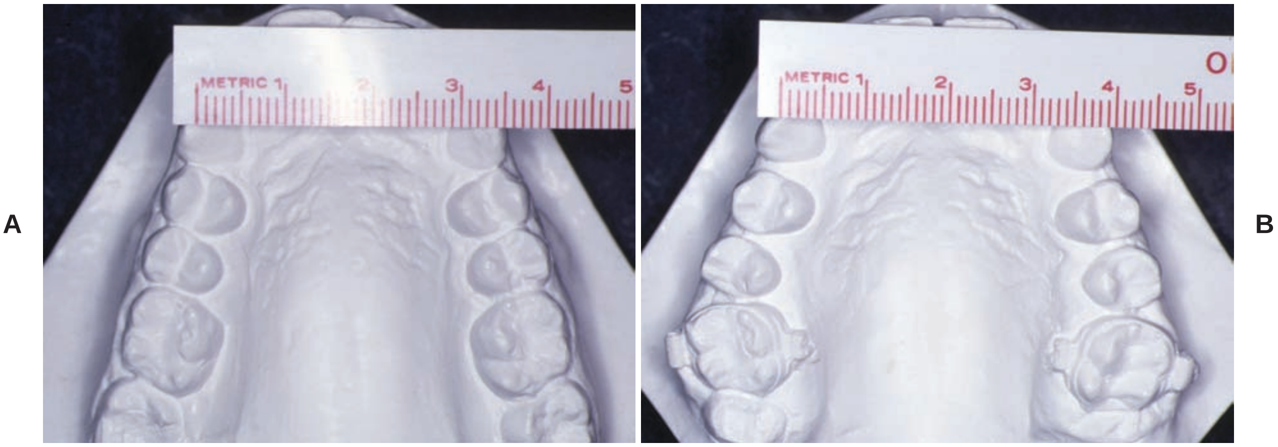

FIGURE 22-8 **A–F,** Molar, second premolar, first premolar, and canine widths before and after the distalization of the upper first molars.

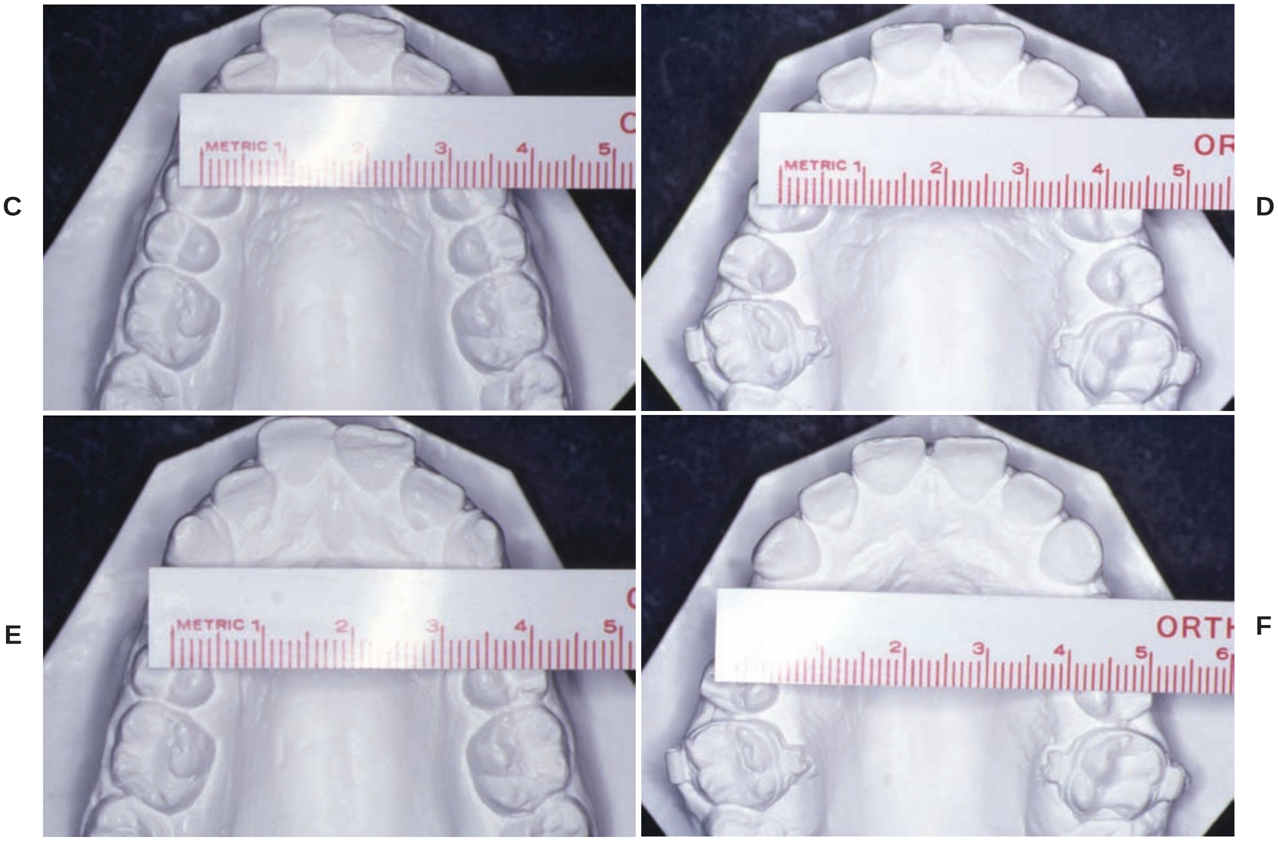

FIGURE 22-8, cont'd

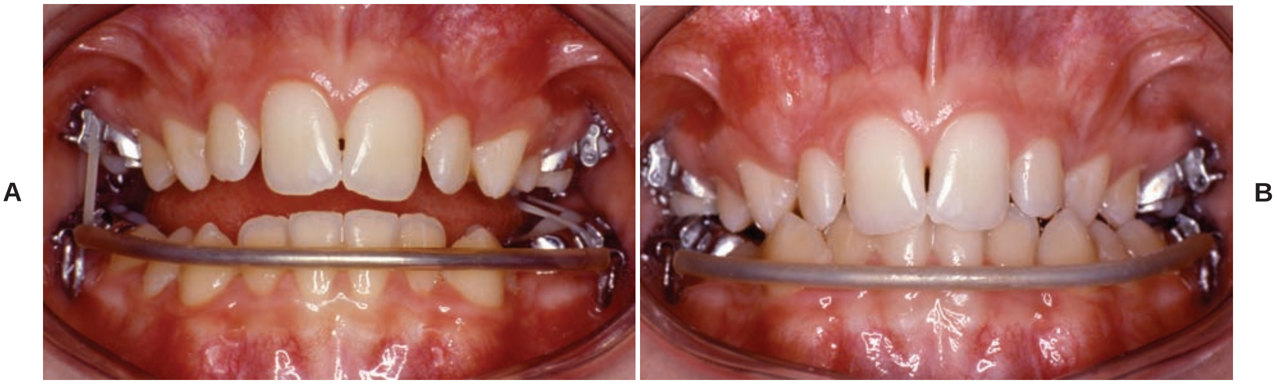

FIGURE 22-9 **A,** View of a transpalatal bar used to correct unilateral crossbite. Normally, a vertical elastic is used to maintain occlusion, and a cross-tooth elastic is used on the crossbite side to increase lateral movement of the upper molar. **B,** After correction of the crossbite.

progressive grinding of the primary molars to reestablish an occlusal contact between the upper and lower first molars. Treatment was carried out until the anterior openbite was closed (Figures 22-12 and 22-13).

At this time, treatment was discontinued and patients were reevaluated. Pretreatment and posttreatment cephalometric mean values revealed a reduction of both sagittal and vertical skeletal problems. Functional improvements were observed in all subjects. Space was gained in both upper and lower arches in all cases. Changes during the interceptive treatment helped in a subsequent definitive phase II treatment to finish the cases without extracting teeth (Tables 22-1 and 22-2).

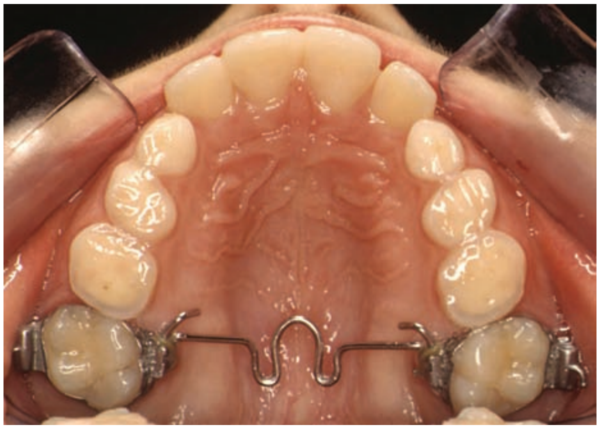

FIGURE 22-10 Occlusal view of two extra loops that can be added to the Coffin loop on a low palatal bar for comfort.

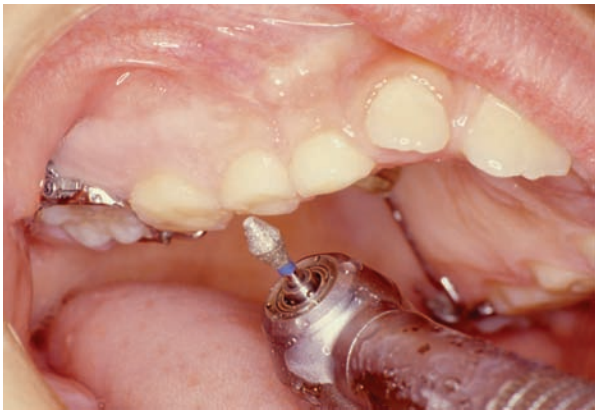

FIGURE 22-11 In mixed dentition the orthodontist can grind the primary molars to prevent molar eruption.

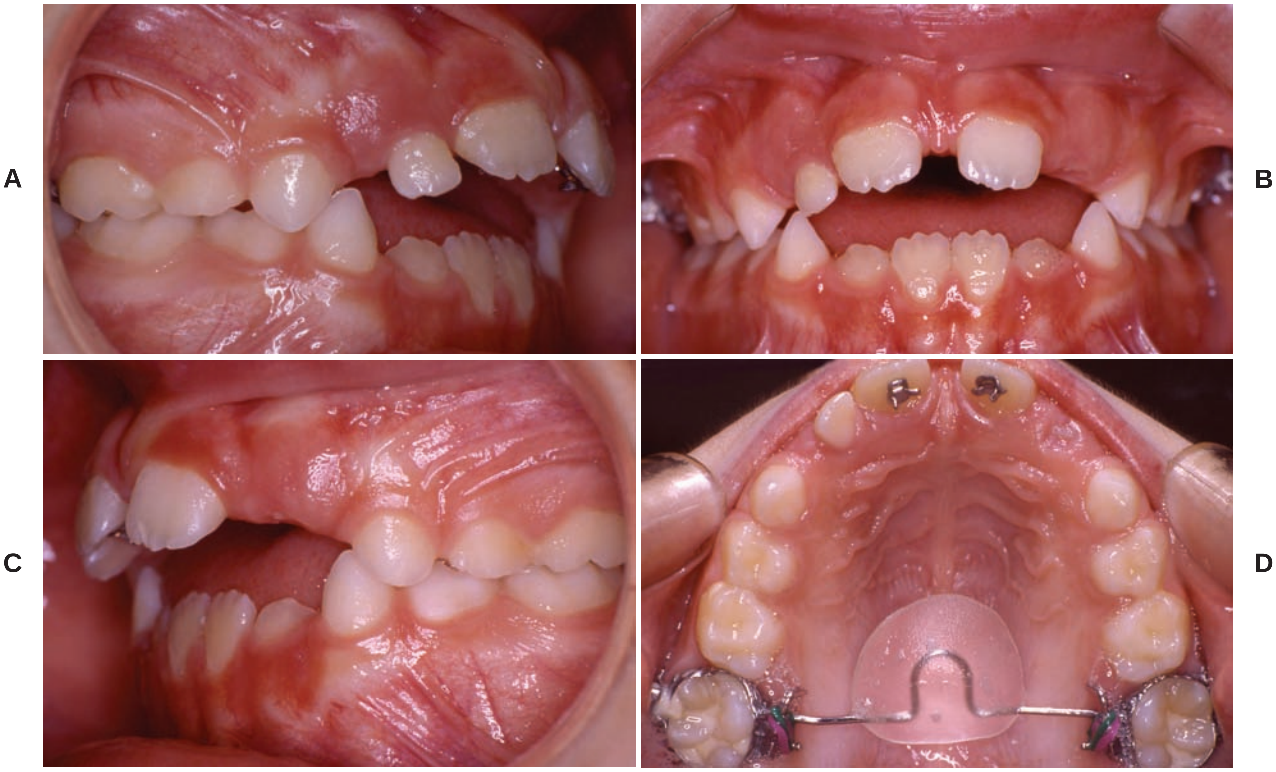

FIGURE 22-12 **A–D,** Treatment of the openbite in early mixed dentition. A low palatal bar with an acrylic pad around the Coffin loop to enhance upper first permanent molars' vertical control. Lingual cleats have been bonded on the lingual surface of the upper incisors to discourage thumb sucking and as a reminder for tongue positioning during swallowing and speech.

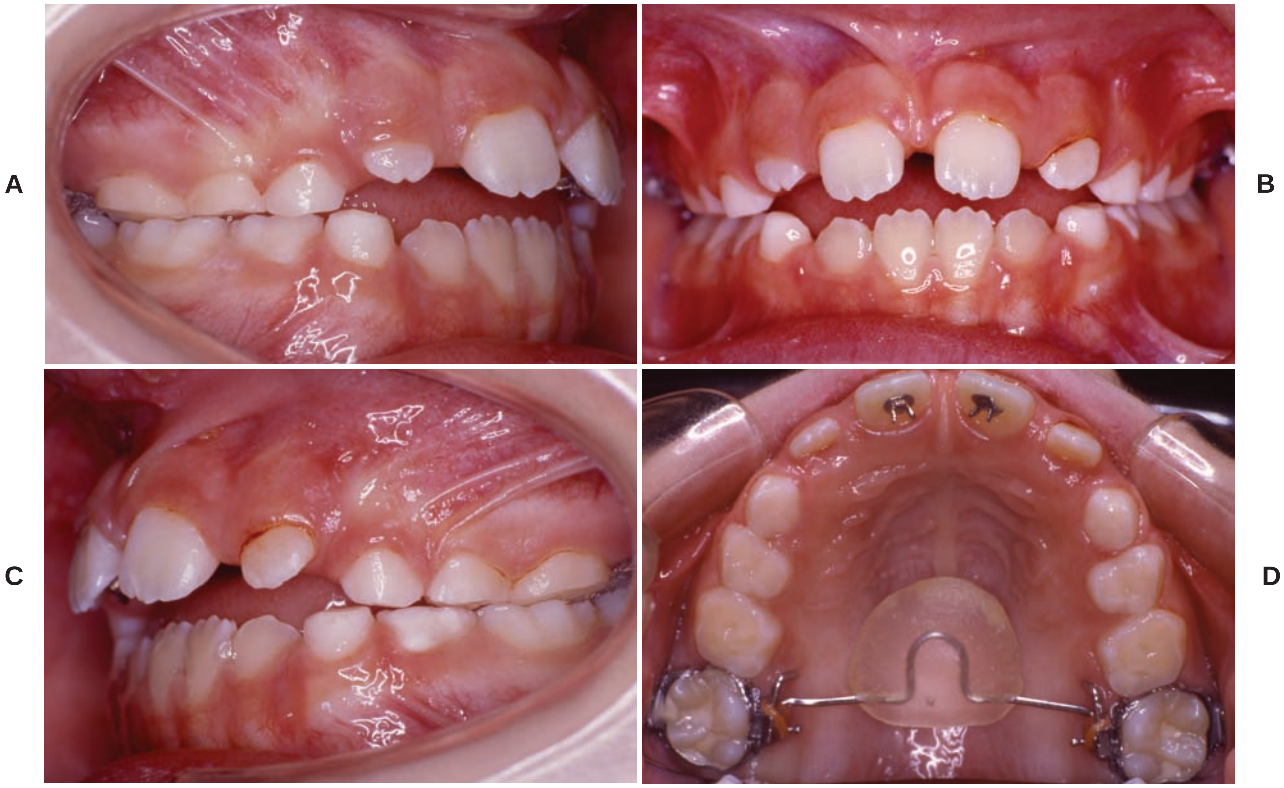

FIGURE 22-13 **A–D,** Bite closed after treatment with palatal bar, high-pull headgear, and grinding of the deciduous molars and canines.

TABLE 22-1 Pretreatment and Posttreatment Average Cephalometric Values Found in the Female Group

Female	Pretreatment Mean ± SD	Posttreatment Mean ± SD
Sagittal		
SNA	82 ± 3.92 degrees	81.31 ± 3.73 degrees
SNB	76.92 ± 5.0 degrees	77.62 ± 4.35 degrees
ANB	5.08 ± 2.32 degrees	3.69 ± 2.02 degrees†
MDB body/ ACB	0.83 ± 0.17	0.97 ± 0.04
Vertical		
SN/ANS-PNS	8 ± 3.46 degrees	8.92 ± 3.04 degrees
ANS-PNS/ GoGn	32.38 ± 3.23 degrees	30.54 ± 2.60 degrees*
SN/GoGn	40.38 ± 4.11 degrees	39.38 ± 4.07 degrees*
PFH/AFH	0.61 ± 0.05	0.61 ± 0.04*
SN/ArGo	87.62 ± 5.33 degrees	89.23 ± 5.31 degrees
Gonial angle	134.77 ± 3.00 degrees	133.85 ± 2.58 degrees
LAFH	67.38 ± 2.60 mm	67.69 ± 2.32 mm
Dentobasal		
1/ANS-PNS	115.38 ± 8.66 degrees	111.85 ± 4.29 degrees
1/GoGn	93.92 ± 9.78 degrees	97.23 ± 12.21 degrees
Dental		
Overjet	4.92 ± 3.05 mm	3.27 ± 2.16 mm
Overbite	(–)4.19 ± 2.63 mm	1.5 ± 1.22 mm*
Interincisal	119.15 ± 11.17 degrees	124.31 ± 7.62 degrees

*Wilcoxon analysis with statistical significance of $p < .01$.
†Wilcoxon analysis with statistical significance of $p < .05$.

TABLE 22-2 Pretreatment and Posttreatment Average Cephalometric Values Found in the Male Group

Male	Pretreatment Mean ± SD	Posttreatment Mean ± SD
Sagittal		
SNA	81.91 ± 3.98 degrees	82.33 ± 2.93 degrees
SNB	77.41 ± 4.79 degrees	79.75 ± 3.55 degrees*
ANB	4.5 ± 1.51 degrees	2.58 ± 0.99 degrees*
MDB body/ ACB	0.84 ± 0.16	0.96 ± 0.05
Vertical		
SN/ANS-PNS	8.25 ± 3.36 degrees	9 ± 2.34 degrees
ANS-PNS/ GoGn	31.33 ± 3.11 degrees	29.58 ± 3.12 degrees*
SN/GoGn	39.58 ± 4.58 degrees	38.58 ± 4.14 degrees*
PFH/AFH	0.61 ± 0.05	0.62 ± 0.05
SN/ArGo	86.58 ± 4.1 degrees	87.42 ± 4.19 degrees
Gonial angle	132.16 ± 3.37 degrees	131.33 ± 2.74
LAFH	65.33 ± 3.31 mm	65.25 ± 2.38 mm
Dentobasal		
1/ANS-PNS	117 ± 7.43 degrees	112.25 ± 4.71 degrees
1/GoGn	94.5 ± 10.3 degrees	94.25 ± 9.59 degrees
Dental		
Overjet	4.96 ± 2.72 mm	2.63 ± 1.58 mm
Overbite	(–)4.5 ± 2.15 mm	1.63 ± 0.57* mm
Interincisal	118.33 ± 10.97 degrees	123.83 ± 7.59 degrees

*Wilcoxon analysis with statistical significance of $p < .01$.

Torque. Several mechanics tend to extrude or to make more prominent molar palatal cusps (i.e., high-pull headgear, expansion, intrusion arches). Other mechanisms tend to extrude buccal cusps (i.e., cervical headgear, constriction).The PB allows an excellent control of upper molar torque. Buccal root torque is more often required because it helps keep palatal cusps high and away from occlusal interference (Figure 22-14). This third order bend tends to extrude the upper molars. If control of the extrusive component is needed, the PB should be kept low and/or a high-pull headgear could be added to upper molars.

Anchorage. After space has been created, control of the upper molars is crucial. In this biomechanical sequence, three-dimensional control is achieved with the BP alone or with the use of extraoral forces.

Extraoral Force. In this nonextraction approach, extraoral forces were used during most of the treatment. During the space-gaining phase, headgear was applied with the PBs and eventually with the removable plate to distalize upper molars in a bodily fashion. During the second phase, when the spaces were used to finish up the case, extraoral forces helped to maintain posterior anchorage. The two types of extraoral forces were the occipital force (high-pull headgear) and the cervical force (low-pull headgear).

Occipital Force. High-pull (occipital force) headgear traction force was exerted from above the occlusal plane and thus had both distalizing and intrusive effects. Occipital force was used in all those cases where molar vertical control was important. Malocclusions with dental openbite tendencies, hyperdivergent skeletal patterns, and biomechanical systems that tended to extrude upper molars were some of the more common clinical conditions that might require a high-pull headgear. The high pull was applied to upper first molars by means of a facebow with the outer bow of the same length of the inner bow. The inner bow was passive to the molar tubes; the outer bow was bent upward so that the point of force application and the line of force lay above the upper molar center of resistance (Figure 22-15, *A*).

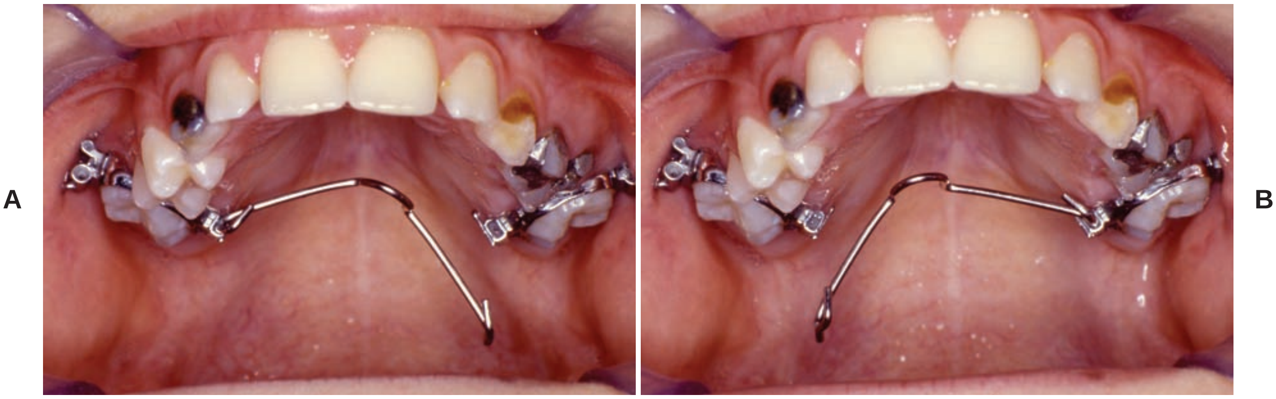

FIGURE 22-14 **A,** To achieve palatal root torque, both terminals are twisted so that when inserted into the right molar, the left (or opposite) terminal stands low to its sheath. **B,** When the transpalatal bar is inserted into the opposite side, it stands low to the right side.

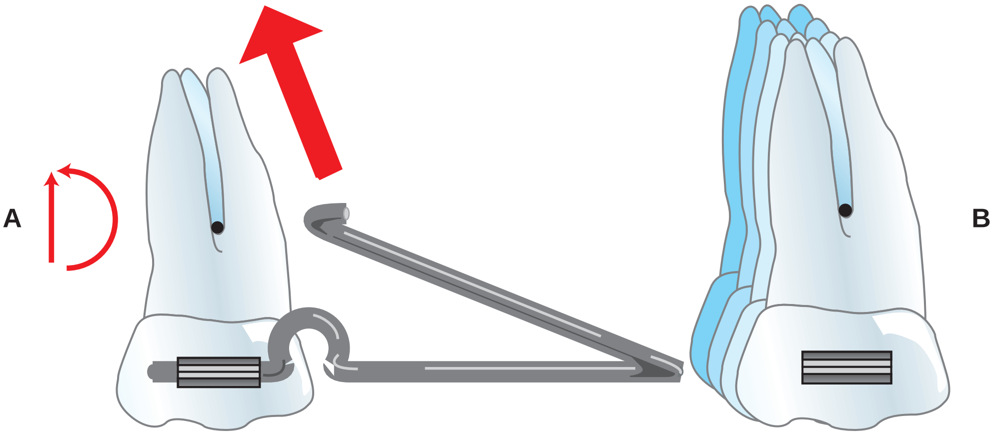

FIGURE 22-15 **A,** When the high pull is applied to upper first molars by means of a facebow with the outer bow the same length as the inner bow, the point of force application and the line of force lie above the center of resistance of the upper molar. **B,** When used with the Cetlin plate, the high-pull headgear allows a backward and upward bodily movement of the molars.

The appliance was adjusted to produce a force system that tended to incline the molar roots distally and intrude upper molars. When used with the Cetlin plate, the high-pull headgear allowed a backward and upward bodily movement of the molars (Figure 22-15, *B*).

Cervical Force. The cervical gear traction force was exerted from below the occlusal plane and had extrusive as well as distalizing effects. Cervical force was used in cases involving a dental deep bite and a skeletal hypodivergent pattern or, generally, when vertical control of the upper molars was not crucial. The appliance consisted of a facebow in which the outer bow was longer than the inner bow and was bent upward so that both the point of force application and the line of force lay above the upper molar center of resistance (Figure 22-16, *A*). When this appliance was combined to the removable plate, the molars were moved bodily backward and downward (Figure 22-16, *B*). Forces of occlusion might limit the amount of extrusion, and favorable condylar growth could compensate for molar extrusion.

Clinical Management of Headgear. Extraoral forces were applied to upper first permanent molars as soon as the molars had been rotated with PBs, when facebows could be easily inserted into molar tubes. When headgear was used together with a PB, the inner bows had to be passive to molar tubes. When the headgear was used alone, the inner bows of high-pull device should have been slightly constricted, whereas those of low pull should have been expanded to prevent the upper molars from rolling out or in.

Facebows had to lie on lower lip. In this way, when traction units were applied, the facebow lay right at the level of labial rim and was comfortable for the patient (Figure 22-17). This confirmed that desired moment was being applied to the molars. The force system could be evaluated more accurately with a headplate taken with the appliance in place. If the facebow had two canine hooks on their inner bows, a light elastic (L10) could be applied to fit on the labial screen of the Cetlin plate to increase anterior anchorage.

Extraoral forces had to be about 150 *g* per side to exert orthodontic and not orthopedic effects. The devices had to be worn at least 12 to 14 hours a day, and at each appointment, the headgear had to be checked to ensure that it was applying the desired force system. The facebow had to be kept a safe distance from the upper front teeth and the screen of the plate. For the patient's safety, the neck pad and the occipital cap had to have breakaway traction units.

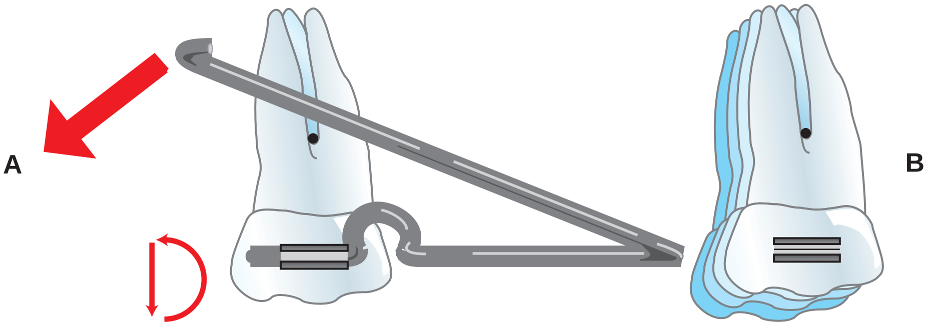

FIGURE 22-16 **A,** In cervical gear traction force the point of force application and the line of force lie above the center of resistance of the upper molar. **B,** When this appliance is combined to a removable plate, the molars are moved bodily backward and downward.

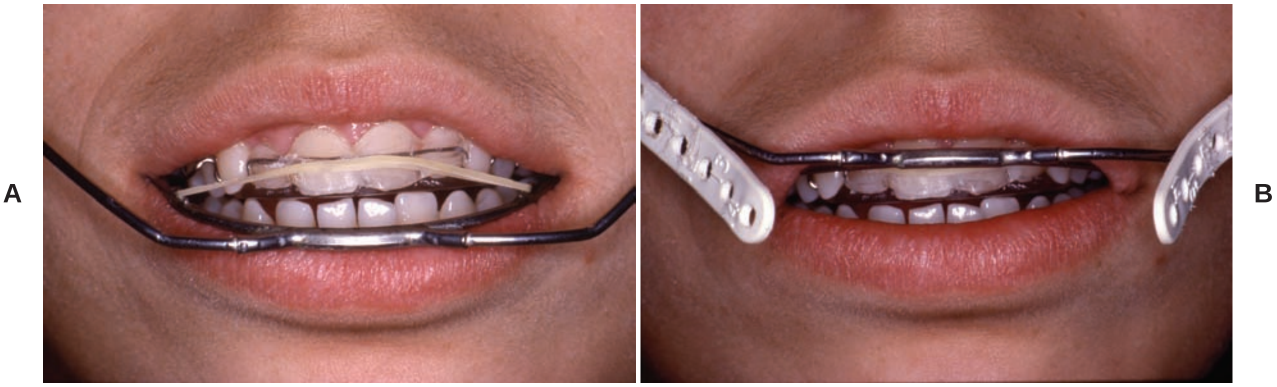

FIGURE 22-17 **A,** Facebow adjusted to lie on the lower lip. An elastic extends from the inner headgear bow to the labial aspect of the removable appliance to increase anterior anchorage. **B,** When traction is applied, the facebow goes to the level of the labial rim, which is more comfortable for the patient.

The Class II relationship was corrected by moving the maxillary teeth distally until the patient closed in a super, or overcorrected, Class I occlusion and mandibular forward growth had occurred. The maxillary molars were distalized initially, and the premolars and anterior teeth were treated later. Distalization was accomplished by the combination of (1) headgear and a PB or (2) headgear and the distalizing Cetlin plate.

Distalization was accompanied by rotation or overrotation of the molars, which significantly improved intercuspation (this technique is described in the following section).

The Removable Distalizing Plate. The removable distalizing plate was used to continue distalization of the upper molars when a "super Class I" relationship could not be obtained using only PBs and headgear. This plate was designed to apply a gentle, constant force of approximately 30 *g* to the upper first permanent molars with minimal reaction on the upper front teeth. However, its forces might tend to incline molar crowns distally and extrude the molars. For this reason, it always had to be used in conjunction with an extraoral force to control molar roots, ensure vertical control, and thus obtain the desired distal bodily movement of the molars.

The plate was composed of the following three parts (Figure 22-18):

1. *The active part:* two 0.028-inch stainless steel distalizing springs with arms that lay against the mesial surface at the gingival level of the upper first permanent molars
2. *The retention part:* an anterior 0.017- × 0.025-inch arch covered by a labial screen and having two Adams clasps on the first premolars or the first deciduous molars
3. *The anterior bite plane:* disclusion aids in the distal movement of the upper molars and in the leveling of the curve of Spee by the lip bumper

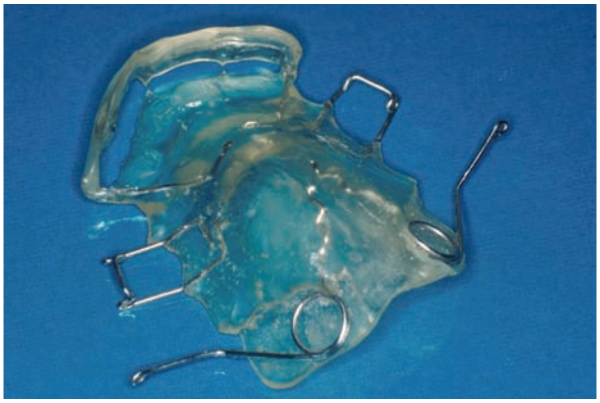

FIGURE 22-18 The removable distalizing plate: anterior biteplate, molar distalizing springs, Adams clasps for the first premolars or deciduous molars, and labial screen, which covers the incisors.

Clinical Management of the Distalizing Plate. The distalizing plate had to be worn 24 hours a day except for meals and hygiene. It always had to be used with the extraoral force to control molar roots and obtain a distal bodily movement. The springs had to be very lightly activated. An activation of 2.0 to 2.5 mm per side gave approximately 30 *g* of distal force either bilaterally or adjusted on alternate sides, as it was done with the PB. Greater activation only increased the chance of molar tipping and loss of anterior anchorage, resulting in worsening of the overjet. Excessive spring force could dislodge the plate or cause it to fit loosely, exerting little distalizing force. The arm of the spring had never to be bent buccally around the molars because this prevented spontaneous lateral movement of the molars. The anterior bite plane had to articulate with as many lower front teeth as possible and provide a small disclusion of posterior teeth (Figure 22-19, *A*–C). It was not to be included in openbite or hyperdivergent cases.

The acrylic of the plate had never to limit the distal movement of the molars and second premolars. After the first permanent molars had been brought to a super Class I relationship, the Adams clasps were removed and the acrylic palatal to the canines and first premolars was trimmed to allow spontaneous distal movement of these teeth through the action of the transeptal fibers, with no strain on the anchorage. The patient had to continue to wear the plate with springs that were passive against the molars. Retention was provided by the labial shield, which was relined with cold-cure acrylic (Figure 22-19, *D*).

The stability of the plate was to be verified throughout treatment. It had to fit snuggly against the roof of the mouth. A stable plate was more comfortable for the patient and controlled molar movement better. If the patient tended to dislocate the plate with the tongue, a hole could be made into the acrylic to prevent suction. To increase sagittal control of the upper front teeth, a groove was cut into the labial shield to engage a light anterior elastic attached to the inner bow of the headgear.

Lower Arch

Space gaining in the lower arch was gained with the lip bumper. Dentoalveolar widening occurred through a combination of uprighting and lateral growth of the dental arches and alveolar bone induced by the interaction of the tongue and lip bumper. The lip bumper was a lower shield and, therefore, was considered a functional appliance. If used correctly and for an appropriate length of time, this appliance could change the neuromuscular factors that determine the form and the dimension of the lower arch, create space by lateral dentoalveolar growth, and allow spontaneous reduction of the lower crowding and of the curve of Spee. Because it lay in front of the lower incisors, the lip bumper gave support to the

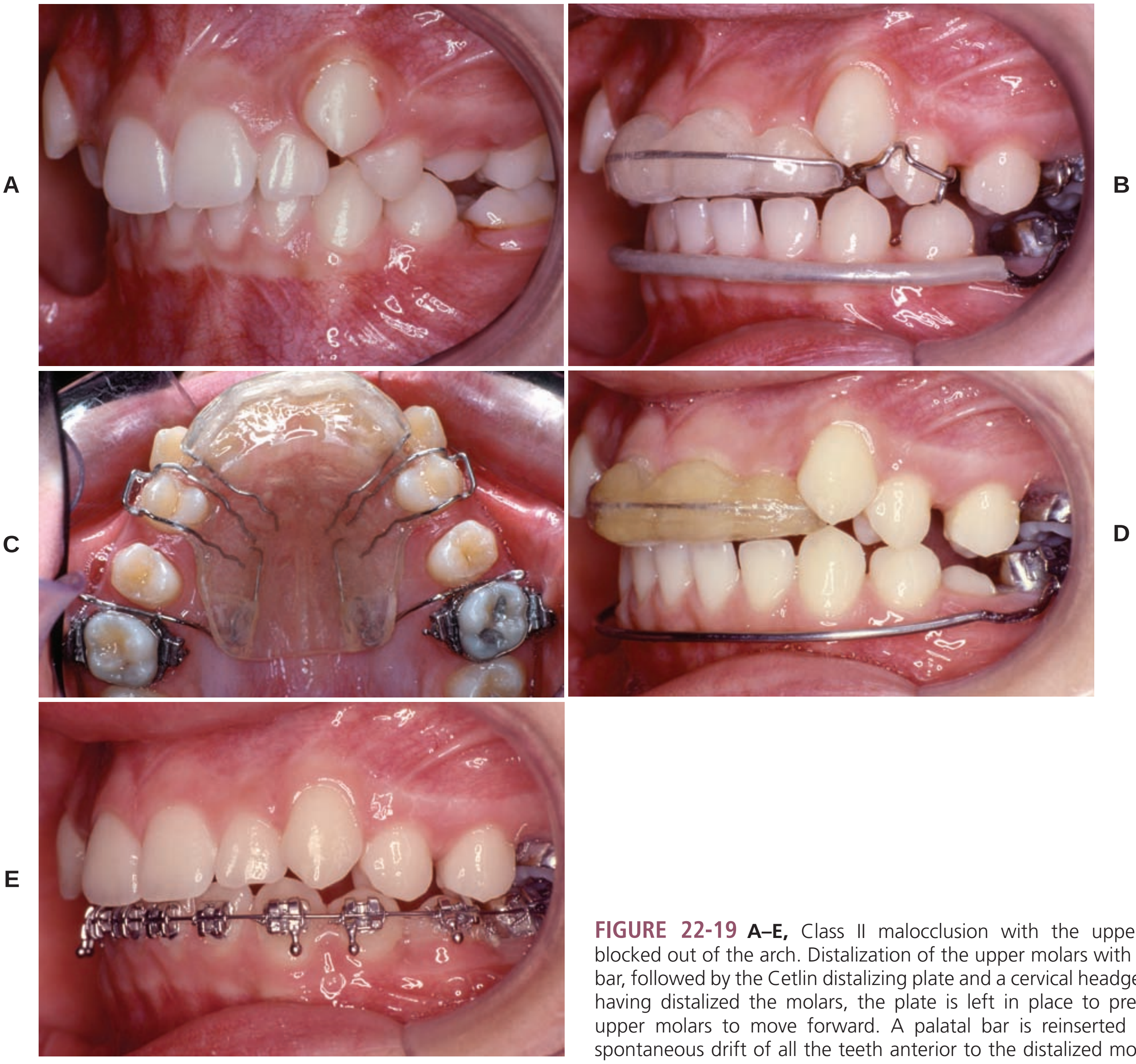

FIGURE 22-19 **A–E,** Class II malocclusion with the upper canine blocked out of the arch. Distalization of the upper molars with a palatal bar, followed by the Cetlin distalizing plate and a cervical headgear. After having distalized the molars, the plate is left in place to prevent the upper molars to move forward. A palatal bar is reinserted to allow spontaneous drift of all the teeth anterior to the distalized molars.

lower lip, improving lip competence, which was an important factor in mandibular growth. Last but not least, the lip bumper transmitted lower lip force to the lower molars, allowing achievement of upright positioning and rotation.

The objectives of the first phase of Cetlin's nonextraction approach in the lower arch were accomplishing rotation and upright positioning of the lower molars, leveling of the curve of Spee, encouraging lateral growth of the arch, and creating space to align all the teeth.[3]

Lip Bumper. The lip bumper is a fixed functional orthodontic appliance. It works by altering the equilibrium between cheeks, lips and tongue and by transmitting forces from perioral muscles to the molars where it is applied (Figure 22-20, *A–C*). The lip bumper has been used for various purposes:

- Molar anchorage[4]
- Therapy of habits[5,6]
- Space gaining in the lower arch.[7,8] The differences in results, which were published in the orthodontic literature,[9,10] probably are related to the fact that several types of lip bumpers are available and they can be used in various ways.[11–13] Cetlin and TenHoeve[3] have described a lip bumper that is easy to use and very effective. All three purposes listed previously can be obtained with it. If used for an appropriate length of time, this lip bumper can help gain an incredible amount of space in the lower arch

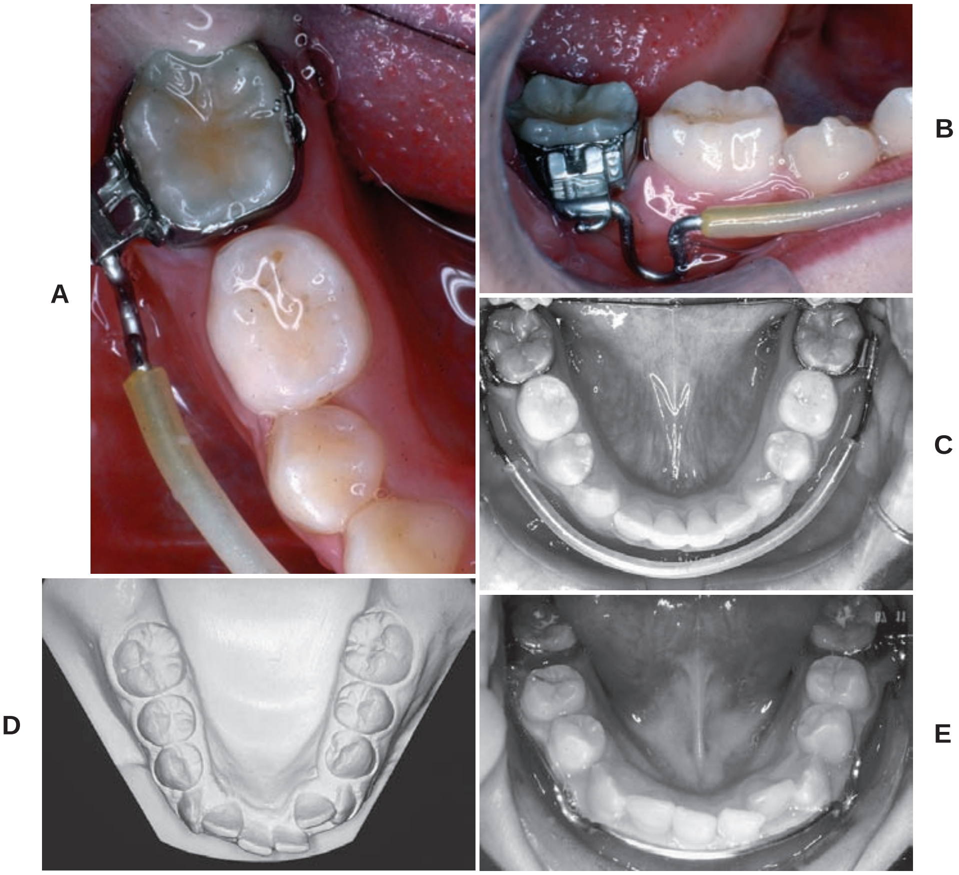

FIGURE 22-20 **A,** Occlusal view of lower right molar and lip bumper. **B,** Buccal view of lower right molar with lip bumper in place. **C,** Occlusal view of lip bumper placement in the mandibular arch. **D,** The mandibular arch before treatment. **E,** The same lower arch after 11 months of lip bumper wear. Note the space gained from dentoalveolar widening and reduction of incisor crowding.

while maintaining good control of the molars and incisors (Figure 22-20, *D, E*).

Characteristics of the Lip Bumper. The lip bumper has a removable part and a fixed part. The fixed part is composed by two molars bands cemented to first or, if possible, second molars with 0.045-inch tubes. These tubes have a 4-degree mesial offset to facilitate insertion and a stepout to prevent gingival impingement. The removable part is essentially composed by a 0.045-inch stainless steel wire that runs in the lower vestibule from molar to molar between teeth and lip and cheeks.

Cetlin[3] has described two different lip bumpers. One type, which has been used since the early days of his practice, is custom made for each patient. It has two loops at the molar level that allow modifications of the appliance during therapy. The second type is preformed and available in different sizes (Figure 22-21). It has four loops, two at the molar level and two at the canine level. The two additional loops give a better shielding effect in the canine region and allow the use of Class III elastics in more severe cases.

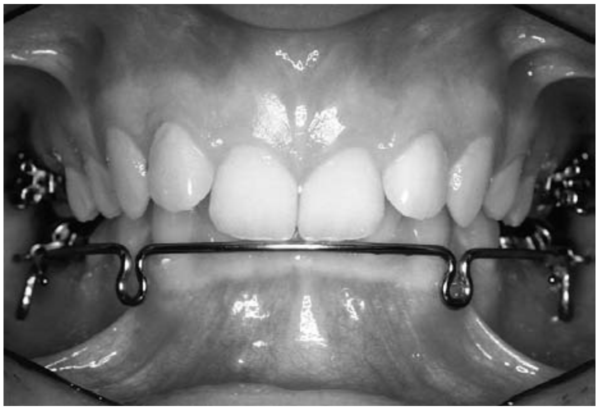

FIGURE 22-21 Preformed lip bumper with four loops: two adjustment loops mesial to each molar and two in the canine area. The additional loops provide a better shielding effect in the canine area and can be used for Class III elastics in more severe cases. The custom-made bumper (shown in Figure 22-20, **C**) has only two loops (mesial to each molar).

Fitting the Lip Bumper. The lip bumper must keep cheeks and lip away from the lower dentoalveolar area, and this shielding effect must be verified at each appointment. The lip bumper should be wider buccally and flatter anteriorly than the natural archform it is desired to produce because the dentoalveolar widening and reshaping are induced by the tongue and lip bumper without direct appliance force except for the contact at the molar tubes. The lip bumper should not exert any expansion or contraction on the molars. It must be easy for both the clinician and the patient to insert and remove. As the arches anterior to the molars respond to the reshaping and widening of the lip bumper, they take on wider natural archform.

Guidelines are given next for obtaining an optimal adaptation of the appliance:

1. **Transverse position:** The wire must be 2.0 mm from the lower canines and 3.0 to 4.0 mm from the premolars. Protection of the canine area is crucial, and the four-looped bumper definitely is more effective.
2. **Sagittal position:** The lip bumper should not be more than 1.0 to 2.0 mm away from the labial surface of lower incisors. The position offers good support of the lower lip for the anterior seal without rendering the appliance uncomfortable.
3. **Vertical position:** In the lateral segments, the wire must be positioned generally at the middle third of premolar and canine crowns. In the severest cases, in which good vertical control is necessary, the bumper can be adapted to rest deeper in the vestibule. The cheeks override the bumper during function, producing an intrusive force on lower molars. In the anterior region, depending on the overbite, the bumper can be positioned at three different levels with respect to the incisor crowns.
    - **Incisal edge:** This position usually is used during the initial phase of treatment. It helps to upright mesially inclined molars because the lower lip tends to lift the anterior part of the bumper, creating a long lever effect on the molars.
    - **Middle third:** This is the position to use when a shielding effect on incisors is desired. The lower lip is kept away from the teeth, altering the equilibrium in favor of the tongue. The incisors slowly translate labially.
    - **Gingival level:** This level is used when the orthodontist does not want to alter the equilibrium between centripetal and centrifugal forces. Because the incisors are still under the lower lip action, they maintain their position. The lip bumper must be kept very close to the incisors.

Activating the Lip Bumper. After space has been obtained in the lower arch and bonding of the lower arch has been planned in a few appointments, the bumper can be activated to correct the rotation of the lower molars. A slight lingual bend is placed in one terminal (or both, if necessary), adding approximately 1.0 mm of expansion to counteract the lower molar tendency to tip lingually.

To prevent any change in the activation, the bumper is tied in with an elastic chain. This toe-in makes it difficult for the patient to remove the appliance. Activation of the lip bumper is best postponed until near the end of the space-gaining phase because at that stage the molars are easier to control and the patient will tolerate it better after a few months of wear.

In a few circumstances, the appliance can be expanded if the lower molars are lingually inclined. The activation should not exceed 1.0 to 1.5 mm per side.

Clinical Management of the Lip Bumper. The appliance must be worn 24 hours a day and should be removed only for meals and hygiene. Although patient adaptation may not be optimal during the first month, the appliance should be worn as much as possible during that time. The two-looped bumper has the shrink tubing that gradually discolors as the patient wears the device. If cooperation is still a problem after a few months, the appliance can be tied to molar hooks with an elastic chain.

If the appliance has been well fitted, a red line can be seen on the inside of the cheeks and the lower lip where the wire runs. If the lip bumper is too distant from the teeth, ulcers may appear. In such cases, the appliance is removed for a day or two, lesions heal, and treatment is restarted with an appliance that runs closer to the teeth. At each appointment, the bumper is checked to ensure that it is still passive on the molars and that it maintains the desired distance from the teeth. The patient may be given a card showing the positions of the two terminals and should be advised always to check these positions before inserting the appliance. This prevents undesirable mechanical expansive forces on the molars. At the end of the space-gaining phase, use of the bumper is discontinued. If it is needed for anchorage problems, it is readapted so that it does not contact brackets, while not being too procumbent.

Class III Mechanics. If the upper arch has been overcorrected and the upper molars are in super Class I relationship but space is still needed in the lower arch, the lip bumper's action can be enhanced by the use of light (2 to 3 ounces per side) Class III elastics that are driven from upper first molars to the bumper's hooks at the canine level. Anchorage on the upper molar can be controlled with a PB, an extraoral force, or both. If lower second molars are present, it is better to bond them and put a sectional between the first and second molars; otherwise, a discrepancy may result between marginal ridges.

EVOLUTION OF THE TECHNIQUE

The Cetlin mechanics, as it has been just described, had some limitations since a good cooperation of the patient for most of the treatment was required. Problems have been encountered mainly with the use of (1) the distalizing plate that needed full-time wear to obtain a bodily distalization of the upper permanent molars as well as a continuous disclusion between the two arches to achieve mandibular growth, leveling of the lower curve of Spee, and lateral dentoalveolar growth in both the upper and lower molar/premolar area, and (2) the headgear that, even if it has always been considered the home appliance to be worn afternoon and night as much as possible, has often been a difficult-to-accept appliance.

Modifications have become necessary to overcome these problems of compliance.

In the early nineties, several distalizing intraoral appliances have been described in the literature. Among them, the Pendulum Appliance presented by Dr. Hilgers seemed to fit perfectly in the Cetlin mechanics. It has replaced the Cetlin Distalizing Plate and, partly, the headgear.

The original Cetlin mechanics has not been drastically changed. The use of the PB as initial appliance in the upper arch has been kept for several reasons:

1. Correction of the first permanent molar position (rotation, torque, etc.) is more easily achieved by the use of a PB and no anterior anchorage is required.
2. Starting molar movement with a PB and then applying distalizing forces with a pendulum may give better anchorage control and make the pendulum more effective.

The pendulum as described by Hilgers has been slightly modified to better satisfy the therapeutic needs. The original appliance is anchored on all four premolars. In this way, the second premolars are not free to move distally and laterally together with the first permanent molars as with the Distalizing Cetlin Plate. For this reason, anterior anchorage has been limited to the first premolars (Figure 22-22). The applied force to distalize molars has been notably reduced to the level of the force produced by the Cetlin Distalizing Plate. An uprighting and expansion force has been added as described by Byloff et al. In this way, molars are distalized in a more bodily fashion, and the second premolars are free to move distolaterally together with the first molars thanks to the transeptal fibers as in the original Cetlin mechanics.

The sequence of treatment has gradually changed in the following way:

- Crossbite correction, as well as rotation, distalization, and torque of upper molars with one or more palatal bars
- Molar distalization with the modified pendulum appliance
- Creation of a super Class I molar relationship
- Molar anchorage and control with a PB with a “biscuit-like acrylic button” (Figure 22-23) to upright and intrude molars and to allow spontaneous distal drift of premolars and canines

COMPARISON OF TWO DISTALIZATION METHODS: PENDULUM VERSUS PALATAL BAR PLUS PENDULUM

A clinical study has been carried out at the University of Ferrara to find out whether the combination of the two appliances, first the PB to rotate distolaterally and then the pendulum to distalize the upper first molars, could lead to more bodily movement and therefore minor loss of anterior anchorage. Furthermore, we wanted to verify whether the use of a PB prior to the application of a pendulum would result in less extrusion and better vertical control of the permanent molars, and therefore less clockwise rotation of the mandibular plane.

The study group consisted of 20 consecutively treated patients whose nonextraction therapy was started with a PB to correct rotation, constriction, and torque of the upper first permanent molars and continued with a pendulum to attempt a bodily distal movement of the same teeth. The pendulum used in this group had bonded occlusal rests only on the upper first premolars.

The control group consisted of patients treated with the Hilgers pendulum alone. Lateral cephalograms were taken before (T1) and immediately after (T2) distalization. The T test of the cephalometric data revealed that

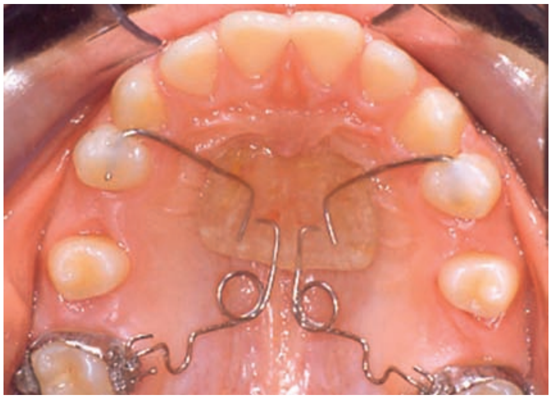

FIGURE 22-22

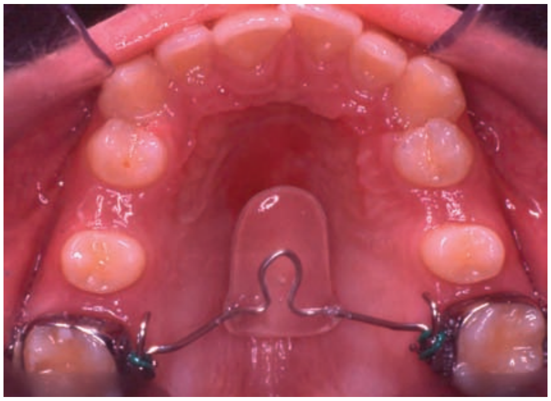

FIGURE 22-23

only the measurement of inclination of the molar axis was significantly altered during distalization in both patient groups. The analysis of variance, however, revealed no statistically significant difference between the two groups.

The use of the PB to initiate molar movement reduced the anterior anchorage needed since the modified pendulum bonded only on the first premolars and produced the same anchorage loss of the classically pendulum designed on all four upper premolars. Moreover, the combined use of PB and modified pendulum gave a better molar vertical control and a faster distalization of the lateral upper segment (molars plus premolars).

MOLAR UPRIGHTING AND VERTICAL CONTROL AFTER DISTALIZATION WITH THE PENDULUM

The distalization of the upper molars with the intraoral distalizing appliances may produce molar distal tipping and extrusion. The pendulum appliance may do so, too. These undesirable effects are corrected with a PB with a large "biscuit-like" acrylic button around the Coffin loop (Figure 22-24).

The appliance is kept in place until molars are uprighted, the marginal ridges discrepancy is corrected, and vertical molar control is recovered.

In another study conducted at the University of Ferrara, growing patients (mean age, 9.5 to 13.8 years) with Class II malocclusions treated with an initial palatal bar, a pendulum, and a PB with this large acrylic button to control molars were analyzed on cephalograms taken at T0 (pretreatment), at T1 (end of molar distalization), and at T2 (end of treatment). In every case, a full correction of the malocclusion had been achieved. Results have shown that ANB and SnGoGn decreased on average, respectively, 3.32 and 1.3 degrees.

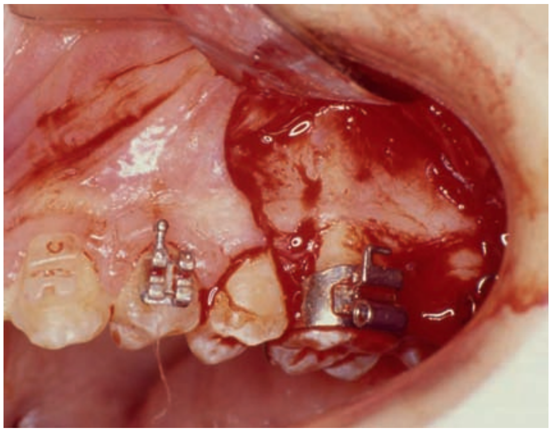

FIGURE 22-24

SEGMENTAL ALVEOLAR CORTICOTOMY TO ENHANCE UPPER MOLAR DISTALIZATION

Corticotomy has long been used in orthodontic treatment to accelerate dental movement and improve its efficacy, and to reduce the appearance of undesired phenomena such as root resorption, loss of vitality and relapse of the corrections carried out. In particular, Suya[15] accurately described the surgical and orthodontic procedures used in the treatment of 395 adult Japanese patients and suggested that most of the therapeutic procedures be carried out in the first 3 to 4 months, before fusion of the tooth-bone units. Suya considered his the best method in conventional orthodontic treatment in that it was less painful, yielded more stable results, and presented fewer root resorption problems than other techniques. In 2001, Wilcko et al.[14] published a case report in which corticotomy was used in conjunction with resorbable alloplastic grafts of demineralized freeze-dried bone in order to increase the amount of alveolar bone, regenerate the bone in the zone of dehiscence and fenestration, and avoid gingival recession resulting from expansion of the arches. These authors found that the fast orthodontic tooth movement was not due to repositioning of single tooth-bone units, as believed by Kole and Suya,[15] but to a cascade of physiological events (area of transitory secondary osteoporosis and greatly reduced bone density) described by Frost as regional accelerated phenomena (RAP).

Clinical research has been conducted on enhancement of distal molar movement by the use of corticotomy. In these ongoing clinical studies, segmental (selective) alveolar corticotomy, limited to upper first and second permanent molars, has been evaluated to see if it may help reduce their resistance to distalization, thus reducing anchorage need and obtaining a more rapid and bodily movement.

The protocol consisted of an initial phase of leveling and aligning (straight-wire appliance with 0.022 slot) up to a 0.018- × 0.025-inch stainless steel wire. At this moment, the segmental corticotomy was arranged.

Lidocaine 2% with epinephrine 1:100,000 was used for local infiltration at the sites of surgery. Buccal and palatal (lingual) sulcular incisions were made, with mesial and distal vertical releases one tooth away from the area to be decorticated. Full-thickness flaps were reflected and any interproximal papillary tissue remaining between the teeth was left in place. Buccal reflection was carried out palatally beyond the apices of the teeth. Decortication was then produced using a rounded bur under ample irrigation. Vertical cuts were produced between the roots of the teeth (first and second permanent molars) to be moved orthodontically and were then connected by horizontal cuts beyond the apices. The cuts ended 1 to 2 mm before the alveolar crest. Scraping of the cortex was then produced both buccally and palatally to create a bleeding bed for the graft. Cortical penetration was carried out on the buccal side of the alveolar site, taking care to avoid damage to the roots of the teeth (Figure 22-25). Bio-Oss was then placed only buccally to cover the decorticated areas (Figure 22-26). In more recent protocols, new piezoelectric blades are being used instead of burs on surgical handpiece. Grafting is being modified by adding VEGF (Vascular Growth Factors).

The flaps were sutured with nonresorbable silk 4-0. After 1 week, on removal of the sutures, two 200 *g* nickel-titanium springs (Sentalloy red GAC) were positioned bilaterally between the permanent first upper molars and the second upper premolars on the 0.018- × 0.025-inch steel wire to distalize the molars.

Following molar distalization, the retraction of the upper anterior group was carried out in 4 weeks by use of Class II elastics on an 0.018-inch Australian Special Plus Begg-Type upper archwire with two helices between lateral incisors and canines. The necessary distalization of the permanent first and second molars was achieved generally in 8 weeks, without needing any anterior anchorage accessories (Class II elastics, Nance buttons, etc.).The distal movement of the two upper molars occurred bodily, with minimal distal inclination of the crown.

The results of these clinical studies showed that corticotomy helped accelerate distalization of the upper molars and promoted a more bodily movement with less need for anterior anchorage. The use of a sliding mechanic, however, requires optimal alignment and leveling of both arches to minimize the friction generated as the molar tubes slide along the wire used (0.018- × 0.025-inch stainless steel) and the occlusal interference created by the lower molars. These mechanics may be difficult to apply in cases in which alignment and leveling of the entire arches cannot be carried out before distalization of the molars. In these situations, segmental corticotomy may be associated with appliances to distalize the upper molars before applying brackets and wires on the premolars, canines, and incisors.

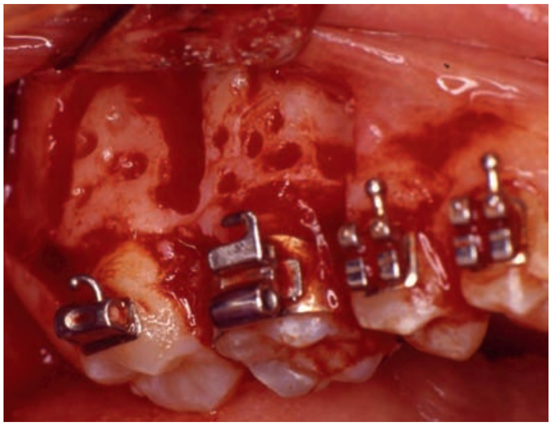

FIGURE 22-25

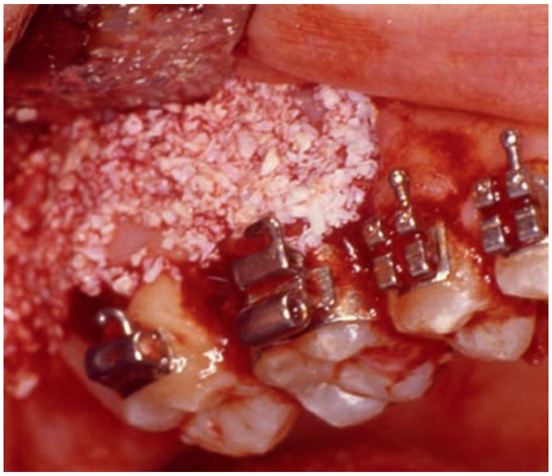

FIGURE 22-26

Space Utilization

In the previous nonextraction sequence, once maxillary molars had been distalized, a generally long period followed to wait for spontaneous drift of premolars and canines. No apparent active treatment was carried out. Bonding of the arch was contraindicated because friction of brackets and archwires and ligatures would have jeopardized the spontaneous movement of teeth in an improved position and would have caused anchorage loss. If indicated, only intrusion of the maxillary incisors was initiated to remove the last obstacle to mandibular repositioning and growth.

The new self-ligating brackets combined with the light small wires seem to overcome these problems and allow bonding of the arches earlier without compromising spontaneous changes. At present, the self-ligating brackets are the best way to standardize force application, wire seating, friction deriving from the “fourth wall”, and everyday clinical maneuvers when changing wires.

The light forces also seem promising in reducing the need for intrusion mechanics.

CONCLUSIONS

Nonextraction treatment mechanics as described by Cetlin has been proved to be a successful way of treating Class I and II malocclusions with crowding. The original mechanics needed to be updated to overcome problems related to patient cooperation and to take advantage of the new appliances and methods. Clinical research will continue to improve the efficacy of this unique therapeutic approach.

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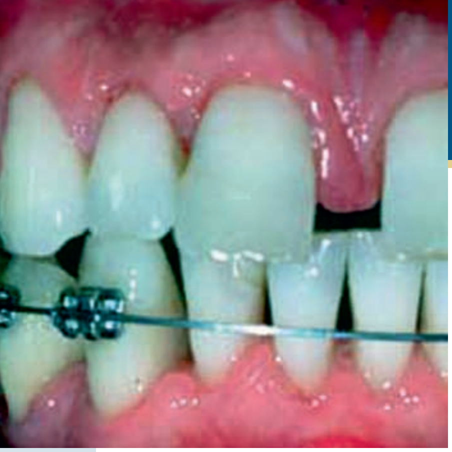

CHAPTER 23

Periodontal–Orthodontic Interrelationships

Robert L. Vanarsdall, Jr., Antonino G. Secchi

OUTLINE

Types of Inflammatory Disease
  Gingivitis: The Reversible Lesion
  Periodontitis: The Irreversible or Destructive Lesion
Mucogingival Considerations
Frenum Considerations, Gingival Hyperplasia, Gingival Retention, and Mouth Breathing
  Mandibular Midline Frenum
  Maxillary Midline Frenum
  Gingival Hyperplasia
  Gingival Retention and Aesthetic Considerations
  Fiberotomy
  Mouth Breathing
  Considerations with Ectopically Positioned and Unerupted Teeth
Summary

As orthodontists enter the twenty-first century, the adoption of evidence-based health care[1] and the invention of new preventive strategies are primary goals. Recent studies have provided compelling evidence of the importance of these two objectives.

For example, statistically significant periodontal differences have been demonstrated in patients with crossbite, excessive overjet, and crowding compared with members of a control group.[2] Another investigation has shown that alveolar bone height in 19-year-old men was reduced in regions of severe malocclusion (8 mm of overjet) compared with the corresponding regions in healthy men who had near ideal occlusion.[3] A recent study evaluated the relationship between the irregularity of teeth and the incidence of periodontal disease; the results indicated that overlapping of incisors is related directly to gingivitis and that this relationship could not be explained simply by an effect on oral hygiene.[4] In a similar investigation involving 15 adults, subgingival bacterial samples were taken from anterior crowded and uncrowded teeth, and control samples were taken interproximally between two aligned teeth on the contralateral side within the same sextant.[5] Statistically, the pathologic levels of bacterial cells were significantly higher in the anterior crowded dentition than in the anterior well-aligned dentition. Furthermore, as crowding increased, the number of subgingival microorganisms increased at a predictable rate. This report offers strong evidence that orthodontics can promote periodontal health and even may prevent periodontal disease. Previous reports tended to conclude that malalignment of teeth could contribute to the establishment of periodontal disease only when poor oral hygiene was a factor.[6]

No matter how talented the orthodontist, a magnificent orthodontic correction can be destroyed by failure to recognize periodontal susceptibility (Figure 23-1). The short- and long-term successful outcomes of orthodontic treatment are influenced by the patient's periodontal status before, during, and after active orthodontic therapy. The long-term prognosis of the natural dentition depends to a significant extent on optimal responses and systemic resistance and on the patient's predisposition to the different clinical forms of periodontal diseases. Periodontal pathogenesis is a multifactorial process, and the orthodontist must recognize the clinical forms of inflammatory periodontal diseases. At the 1989 World Workshop in Clinical Periodontics, a classification system was established for the various types of periodontal infections (microbial combinations), even though these disorders still can be difficult to distinguish by their clinical features.[7] Further information is available in the proceedings of the 1996 World Workshop in Periodontics.[8]

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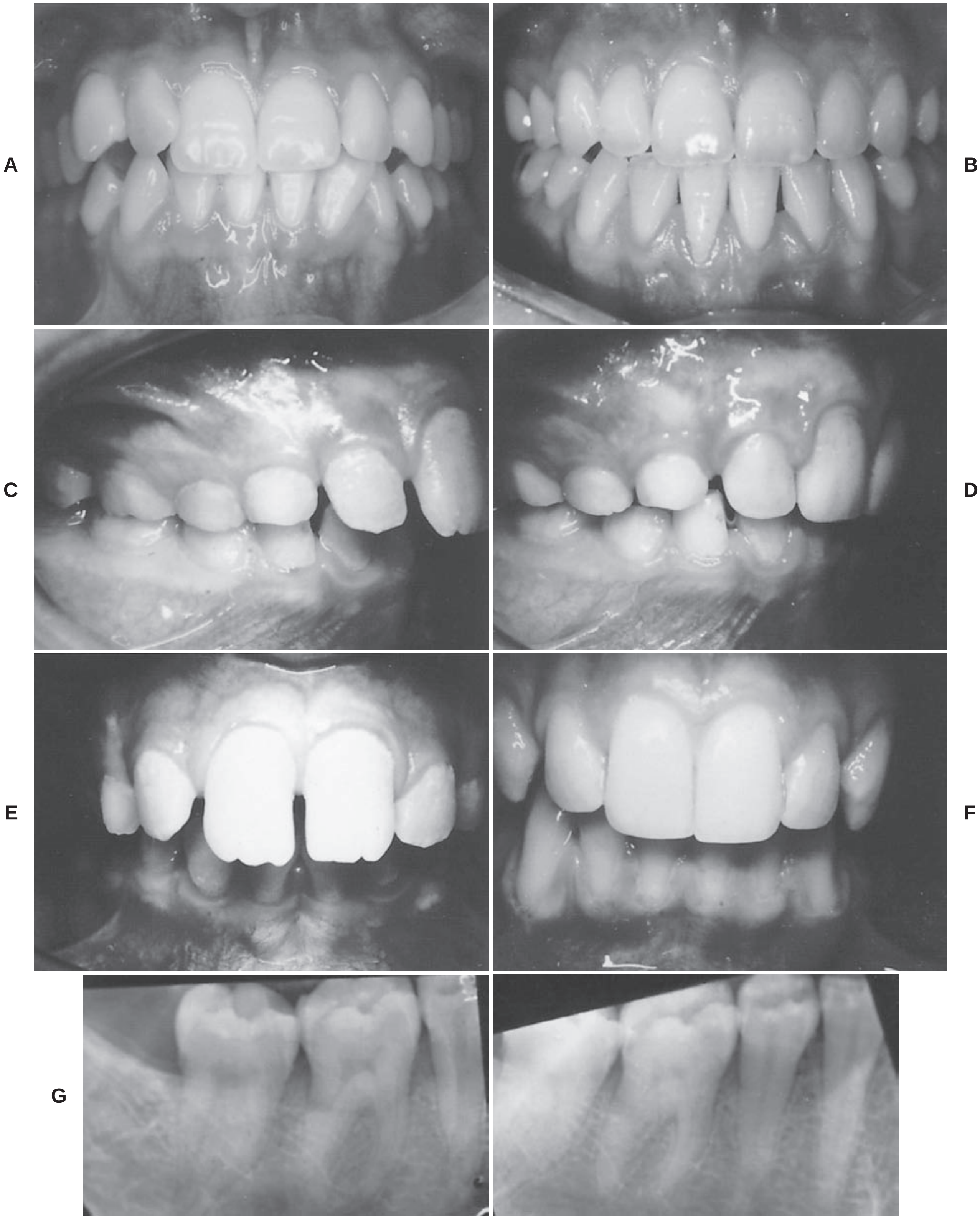


FIGURE 23-1 **A,** A 12-year-old girl before orthodontic treatment. **B,** After removal of the appliances. Note the gingival recession, labial root exposure, and interproximal space under contacts in the mandibular incisor area. **C,** Highly susceptible 9-year-old boy with thin, friable tissue before phase I therapy involving a headgear. **D,** Note the good cooperation, resulting in distalization of the maxillary dentition. **E,** Anterior view before placement of orthodontic appliances. **F,** Anterior view at the end of phase I shows excessive exposure of the anatomic crowns and beginning root exposure on all lower anterior teeth. **G,** Periapical radiographs of a woman's teeth taken before placement of orthodontic appliances.

H

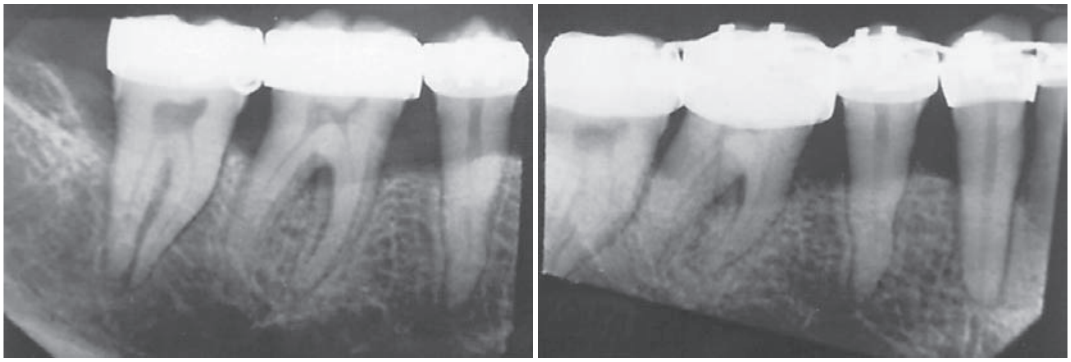


FIGURE 23-1, cont'd **H,** Several months later, progress films are taken because of excessive tooth mobility. Note the radiographic evidence of accelerated bone loss.

TYPES OF INFLAMMATORY DISEASE

Gingivitis: The Reversible Lesion

The accumulation of microorganisms around teeth can cause gingival redness, bleeding, and edema; changes in gingival morphology; reduced tissue adaptation to the teeth; an increase in the flow of gingival crevicular fluid; and other clinical signs of inflammation.[9,10] Obviously, mechanical removal of plaque can reduce chronic gingivitis, but many orthodontic patients may not be motivated to remove the plaque; therefore, plaque removal must be done by the referring dental office or through other professional services such as scaling and thorough tooth cleaning during orthodontic treatment. Patients whose compliance is poor with a manual toothbrush may be more willing to use an electric device (e.g., Interplak [Conair, Stamford, CT], Rota-dent (Professional Dental Technologies, Batesville, AR], Oral-B plaque remover [Boston, MA]) that can improve oral hygiene.[11]

The removal of supragingival bacteria has been shown to have an inhibiting effect on the formation of subgingival plaque; for this reason, antibiotic rinses are recommended for specific problems (e.g., mouth breathing, medication-influenced gingival overgrowth,[12] and hormone-influenced gingivitis). One of the more effective antiplaque, antigingivitis agents is chlorhexidine digluconate; however, the orthodontist must monitor the side effects of reversible staining, tissue response, and taste alterations. Exaggerated gingival overgrowth and response to plaque have been reported with hormonal changes in pregnancy, with puberty, during the menstrual cycle, and in response to steroid therapy and birth control medications.[13]

Gingivitis (without attachment loss) has been classified as having initial, early, and established stages. The initial lesion develops 1 to 2 days after plaque is allowed to remain on the teeth. The established lesion develops weeks later, when inflammation has advanced to proliferation of epithelium into the connective tissue. Only the established lesion can be observed as clinical gingivitis. The important point is that alveolar bone loss has not yet occurred, and one can hope that the lesion can be prevented from spreading into the supporting tissues. Therefore determining the appropriate plaque control interval for the patient is crucial to prevent destructive alveolar bone loss. Pseudo-pockets or gingival overgrowth or enlargement of the gingival margin and papilla, be they drug induced (e.g., phenytoin or cyclosporine) or primarily plaque related, are exacerbated by poor oral hygiene. Constant professional reinforcement is necessary.

Periodontitis: The Irreversible or Destructive Lesion

Although gingival inflammation may be a prerequisite, the actual mechanisms responsible for conversion of gingivitis to periodontitis are still being debated.[14] All forms of periodontitis are marked by loss of connective tissue attachment and usually gingival inflammation. The "episodic burst" form of the disease usually manifests as short intervals of significant attachment loss followed by periodic remission and an indefinite period of inactivity.[15]

Adult periodontitis is the most common form of periodontitis. Studies in the United States show that about half of all teenagers 18 to 19 years old have at least one site with 2 mm or more of attachment loss.[16] The prevalence increases with age: about 80% for individuals 35 to 39 years of age, 87% for those 45 to 49 years old, and more than 90% for persons 60 years old or older. The organisms most often reported that have been associated with adult periodontitis are *Porphyromonas gingivalis, Prevotella intermedia*, and *Bacteroides forsythus*; testing for these organisms is easy.

Prepubertal periodontitis is a rare form of periodontitis that appears soon after eruption of the primary teeth. Prepubertal periodontitis is characterized by severe gingival inflammation, rapid bone resorption, and possibly tooth loss.[17] This disease can appear as a localized condition that affects only several primary teeth or as a more generalized form that affects the primary and the permanent dentition.

Localized and generalized juvenile (early onset) periodontitis arises in the circumpubertal period.[18] Localized juvenile periodontitis has a familial tendency and is marked by severe, rapidly progressive alveolar bone loss that affects primarily the permanent first molars and incisors.[19] Even though these patients have a significant disease condition, they form little dental plaque or calculus, and they may respond well to local débridement supplemented by tetracycline or appropriate antibiotic therapy. Generalized juvenile periodontitis, sometimes called rapidly progressive periodontitis, is considered a problem of young adults, but it may begin at or around puberty. Significant gingival inflammation may occur, as well as heavy accumulation of plaque and calculus around many teeth. Most periodontists use mechanical débridement with antibiotic therapy to resolve the infection.

Rapidly progressive periodontitis occurs in young adults, and the cause and pathogenesis appear to share many of the features of generalized juvenile periodontitis, such as rapid bone loss in some subjects and depressed neutrophil functions.[20]

Refractory periodontitis is a disease classification used to define sites present in patients who continue to be infected with periodontal pathogens and who have a high rate of loss of attachment and tooth loss despite intensive periodontal treatment to prevent bone loss. Any periodontal patient can undergo changes that affect host defenses, or systemic disease may cause a lesion or sites to become recalcitrant. Emphasis on the category refractory may be more important because any of the periodontal diseases can become refractory. Orthodontic patients who have individual sites with recurrent inflammatory episodes usually are placed in this category.

Periodontitis also can be associated with systemic diseases such as diabetes mellitus, cyclic neutropenia, Down syndrome, Papillon-Lefèvre syndrome, inflammatory bowel disease, Addison disease, and combined and acquired immunodeficiency diseases.[21]

In general, one should recognize that children can develop severe forms of periodontitis, but the prevalence of destruction is much less than in adults. Severe bone loss in a child or adolescent also may be an early sign of systemic disease and may indicate the need for medical evaluation.

As is described in Chapter 23, the orthodontic patient may be at greater risk of attachment loss after teeth have become mobile because of tooth movement (Figure 23-1, *G, H*). The orthodontist must recognize and control clinical signs of inflammation and tooth mobility during treatment to prevent extensive bone loss. Periodic monitoring of the periodontal status with probing, microbiologic assessment by immunologic assays, DNA probes, culturing, as well as clinical findings, are useful in determining scaling intervals and detecting potential sites of increased risk of attachment loss. These methods may be used to assess the end point of the effectiveness of scaling and root planing before orthodontic treatment to ensure that no putative pathogens remain. Genetic studies offer potential benefit in identifying high-risk individuals,[22] such as those with neutrophil chemotactic abnormalities who are family members of patients with localized juvenile periodontitis; such individuals are 10 times more likely to develop periodontal disease than most family members.

High-risk Factors. The orthodontist must assess each patient for periodontal factors that may place the patient at higher risk of developing periodontal disease during orthodontic therapy. The clinician must identify susceptible patients and develop strategies to prevent loss of attachment and gingival recession.

A significant dental history could include unsuccessful orthodontic treatment at an earlier age. A patient with a history of previous periodontitis[23] obviously is more susceptible to the disease. Although predicting which sites may progress from gingival inflammation to periodontitis is difficult, those who have had the disease previously are more vulnerable to further bone loss. In fact, in individuals who have had previous bone loss, gingivitis may be a greater threat for further bone loss.[24] No one should begin orthodontic treatment if active destructive sites are present, and a person who has had periodontal disease before should be monitored more closely to prevent new bursts of active sites that may result in rapid bone loss. A small percentage of adolescents (10%) and a much larger group of susceptible adults (50%) must be treated differently. Other risk factors include gingival bleeding from probing, tooth mobility, and thin, friable gingival tissue. Chapter 23 discusses each of these factors. In addition, tobacco use and diabetes mellitus have proved to be risk factors for a higher prevalence of periodontal disease.[25–27]

The orthodontist should record a list of periodontal risk factors for any adult who seeks orthodontic treatment. Risk factors are important, for example, in identifying patients who will need a special management approach with individualized periodontal recall intervals. The orthodontist must control for risk factors before beginning orthodontic treatment so that periodontal problems are less likely to develop. Stress, diabetes mellitus, tobacco smoking, osteoporosis, and genetic predisposition are examples of disease modifiers.[28] Genetic testing could be used as part of risk assessment for development of future disease, and the patient can be informed of the greater risk of developing disease.[22,29]

A risk marker is a characteristic that identifies a patient who is likely to have periodontal disease. In this regard the transverse skeletal pattern may be the most crucial evaluation in gauging the potential for facial gingival recession.

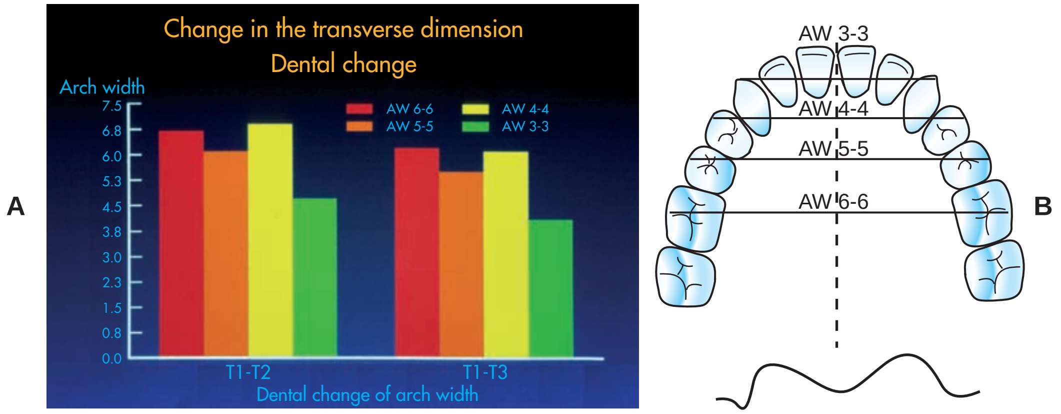


FIGURE 23-2 **A**, A histogram of maxillary dental change, with rapid palatal expansion from T_1 (before expansion) to T_2 (completion of expansion). The second group of bars represents the expansion that was maintained until T_3 (the final period, 10 years after expansion). **B,** Diagram showing the measurement of maxillary arch dental width with electronic digital calipers for each tooth in the 55 expanded cases.

In a study on patients from two private orthodontic practices conducted at the University of Pennsylvania, 55 patients (ages 8 to 13 at the time of treatment with a Haas expander) were recalled 8 to 10 years after rapid palatal expansion (10 to 10.5 mm over 3 weeks) and compared with 30 control patients (matched for age) from the same practices who were evaluated for stability and clinical crown height after edgewise nonexpansion.[30] The patients were assessed from models, Kodachrome slides, and posteroanterior cephalograms made before and at the end of orthodontic treatment; they were recalled 10 years later for examination and new records. The study indicated that of the expanded cases, although the results were stable (Figure 23-2), 11 (20%) showed unusual facial gingival recession on one or more teeth, compared with only 6% gingival recession in the nonexpanded control patients (Figure 23-3). Skeletally, 9 of the 11 patients who had undergone expansion and experienced facial gingival recession had maxillary transverse deficiency and mandibular transverse excess, and the other 2 patients had excessively large mandibles (Figure 23-4). Therefore, in an adolescent patient with a small maxilla and a large mandible, a potential exists to move teeth beyond the envelope of the alveolar process, predisposing the patient to gingival recession. The envelope of discrepancy for the transverse dimension is much more crucial from a stability and periodontal standpoint (see Chapter 23).

A recent study[31] evaluated posttreatment gingival recession in three groups of individuals. At 7 to 10 years after nonextraction treatment, 75 patients treated with rapid palatal expansion therapy (group 1), 22 patients (from the same practice) treated with standard edgewise therapy only (group 2), and an untreated control group (age 17.2 years; group 3) were evaluated for cemental exposure, and posteroanterior cephalograms were evaluated to determine whether a transverse skeletal discrepancy existed between the maxilla and mandible for all subjects. The graph (Figure 23-4, *H*) shows transverse discrepancy (width of the mandible minus width of the maxilla) larger than the normal value (Rocky Mountain normal for age) expressed as a negative number. Twenty percent of all three groups experienced gingival recession. Individuals in each group that exhibited a negative skeletal differential greater than 5 mm (from the norm value) experienced gingival recession. The individuals with a normal transverse skeletal differential in all three groups did not experience recession. Therefore, the transverse skeletal severity is a critical risk marker for identifying patients susceptible to gingival recession and periodontal disease. This is important diagnostic information that can result in a treatment plan that may improve future periodontal health for patients in which the transverse skeletal differential can be corrected.

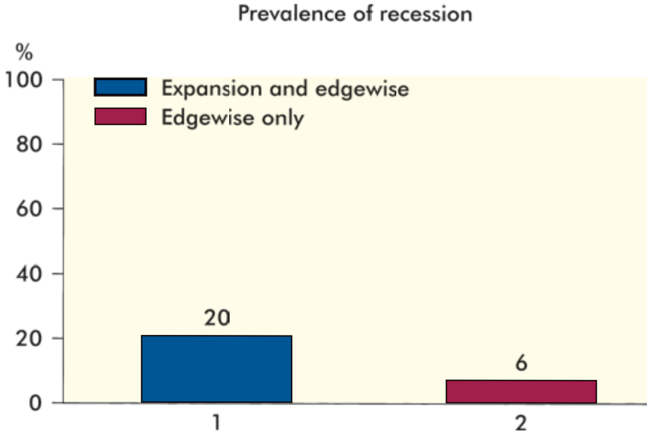


FIGURE 23-3 About 20% (11 of 55) of the expanded cases showed gingival recession, compared with only 6% in the edgewise-only treatment group. The hypothesis that recession is distributed evenly across expanded and edgewise groups was rejected (p = .0025).

Untreated susceptible adults with significant transverse skeletal discrepancy show advanced stages of

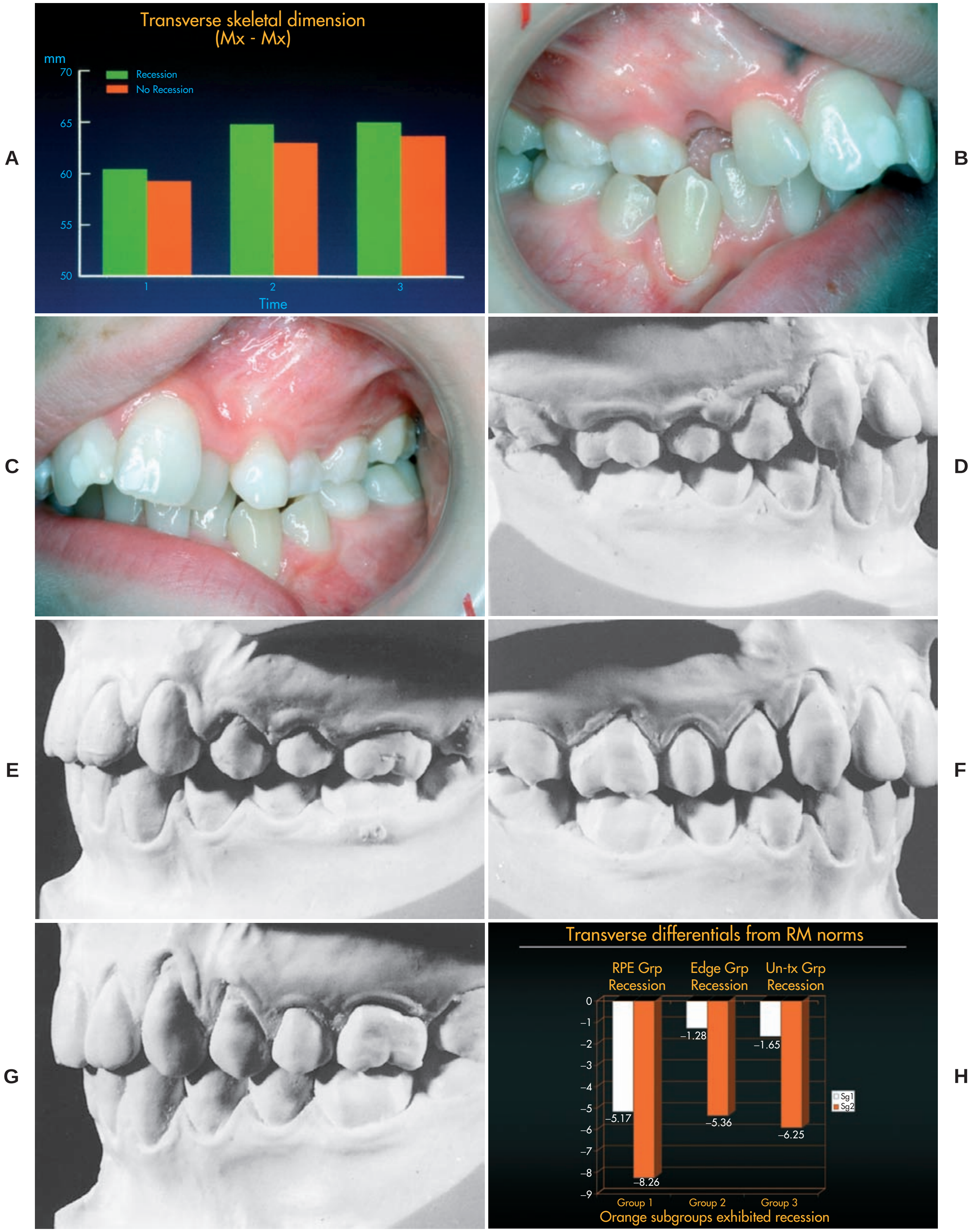

A
Transverse skeletal dimension
(Mx - Mx)
mm
70
65
60
55
50
Recession
No Recession
1
2
3
Time
B
C
D
E
F
G
H
Transverse differentials from RM norms
RPE Grp Recession
Edge Grp Recession
Un-tx Grp Recession
0
–1
–2
–3
–4
–5
–6
–7
–8
–9
–5.17
–8.26
–1.28
–5.36
–1.65
–6.25
Sg1
Sg2
Group 1
Group 2
Group 3
Orange subgroups exhibited recession

FIGURE 23-4 **A,** From the histogram, note that all 55 of the expanded patients at T_1 had a maxillary (Mx to Mx) transpalatal dimension of about 60 mm (deficient) and were expanded at the bony base 4 to 5 mm at T_2 and at T_3 (final period). The basal skeletal increase remained stable and increased with time only 0.33 mm. Little difference was seen in the maxillary skeletal dimension between the patients who showed recession (11 [*dark screen*]) and the patients who did not (44 [*lighter screen*]). The relationship between the maxillary and mandibular widths was a crucial factor in the evaluation, and this proportional evaluation identified the 11 individuals with problems. **B, C,** Buccal views of a 9.4-year-old girl (Class I, Division 1 condition) with a 9-mm narrow maxilla and an excessively wide mandible in the transverse dimension. Observe that there are no crossbites. **D, E,** Models made when appliance was removed. **F, G,** Models made 10.8 years after completion of treatment. Note the gingival recession in the maxillary buccal segments observed years after the appliances had been removed. **H**, This graph represents the mean differentials (difference between Richetts Mx-Mx and Ag-Ag measurements in width) for Rocky Mountain norm values in the rapid palatal expansion group 1, orthodontic-only group 2, and control group 3. *White bars* represent the norm-recession individuals mean differential, and *orange bars* indicate the mean value found for individuals with gingival recession. All groups were found to have individuals with gingival recession, but recession occurred in those with severe transverse skeletal discrepancy greater than 5 mm.

destructive periodontal disease. Hundreds of adult orthodontic retreatment patients have achieved excellent stability from surgically assisted rapid palatal expansion to correct transverse skeletal discrepancy. Growth in the transverse dimension slows severely by 15 years of age and has been reported to be essentially complete.[32,33] Therefore, early orthodontic treatment in the deciduous or early mixed dentition is ideal for correcting transverse skeletal abnormalities orthopedically when growth is significantly active and palatal separation is most effective. Expansion of buccal segments with fixed appliances has limitations and tends to be unstable, regressing toward pretreatment widths.[34]

Orthopedic expansion of the palate has been studied with the use of implants. This study confirmed 50% dental movement and 50% skeletal movement in young children. In adolescents, however, only 35% of the movement was skeletal and 65% was dental.[35] Therefore as the young patient grows older, dental tipping becomes greater, which puts the teeth at higher risk of gingival recession (Figure 23-5, *A, B*). Lindhe[36] has stated that "[when] during orthodontic treatment a tooth is moved through the envelope of the alveolar process … at sites with thin and inflamed gingiva [there is] a risk that gingival recession may occur." The labial plate of bone in the maxilla is thin on the facial surfaces of the teeth (Figure 23-6, *A*). The buccal plate in the mandible is thin in the coronal thirds from the first molar area, moving anteriorly, and is considerably thinner in the premolar/incisor areas (Figure 23-6, *B, C*).

Facial movement of the teeth into thin tissues has been tested in monkeys. Extensive bodily movement of incisors in a labial direction through the alveolar bone (Figure 23-7) resulted in small apical displacement of the gingival margin, which appeared to be thinned by the tooth movement, and reduction of the alveolar bone height.[37] Therefore, less tooth movement and greater orthopedic change in the transverse dimension could be obtained by a surgical adjunct, which has not been shown to create the adverse gingival changes seen with orthopedic expansion in severe or skeletal transverse maxillary deficiency problems. The decision to use a surgical adjunct is based on comparison of the maxillomandibular proportions with individual normal variations. The transverse skeletal discrepancy is corrected (1) to prevent periodontal problems, (2) to achieve greater dental and skeletal stability in adult retreatment cases (Figure 23-8, *A*–*C*), and (3) to improve dentofacial aesthetics by eliminating or improving lateral negative space, which accompanies maxillary transverse deficiency (Figure 23-8, *D*–*G*).

Tissue Response to Certain Types of Tooth Movement. Age-related changes occur in the skeleton and alveolar bone, and adults show a greater lag, or delayed response to mechanical force, than that seen in younger patients.[38] However, teeth move equally well in adults and children, and no evidence indicates that they move more slowly in adults. In a healthy periodontium, regardless of the direction in which a tooth is moved, the bone around the tooth remodels without damage to the supporting tissues. The bone should follow the tooth in changes of position; this principle is used to create favorable alveolar changes in patients with periodontal defects. Significant evidence shows that drawing mesially inclined molars upright reduces pocket depth and improves altered bony morphology[39,40] (Figure 23-9). The bone on the mesial erupts as the molar tips distally. Every dentist has seen teeth erupt, and as a tooth moves occlusally, the healthy alveolar process moves with it (Figure 23-10, *A*). With chronic inflammation, as a tooth erupts, the alveolar bone is lost and the tooth appears to extrude from the periodontal tissues (Figure 23-10, *B*). When molars are uprighted, the connective tissue attachment on the mesial aspect of the molar to the crestal bone creates tension and allows for remodeling of the bone (see Figure 23-9, *C, D*).

Clinically, ranges of force exist that are biologically acceptable to the periodontium. One should remember that because tooth movement is primarily a phenomenon induced by the periodontal ligament, identical forces do not put the same stress on the supporting tissues of different teeth. The root length and configuration, the

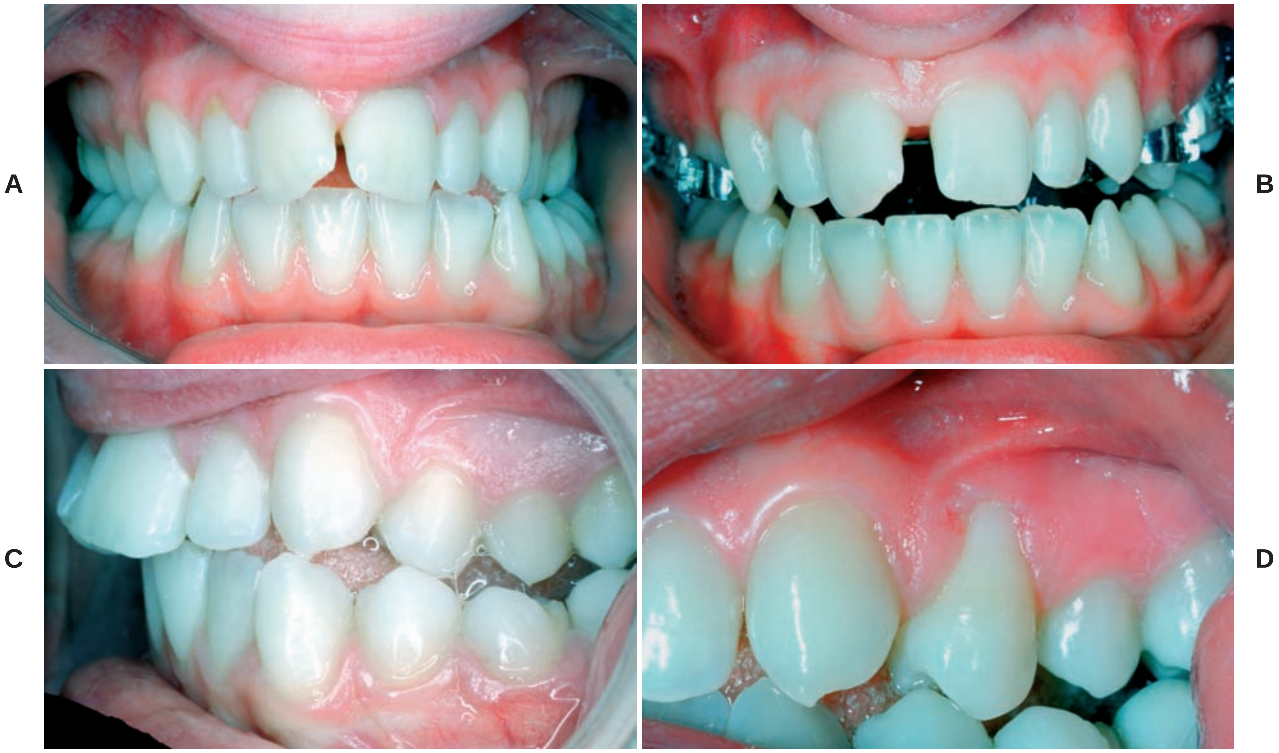


FIGURE 23-5 **A,** A 12-year-old girl before rapid maxillary expansion. **B,** After completion of active expansion. Note the midline diastema and tissue level on the left first premolar. **C,** Note the tissue level on the maxillary left first premolar before expansion. **D,** Several weeks after expansion. Note the 3 to 4 mm of recession on the first premolar, which has been reported as an initial complication with rapid palatal expansion treatment.

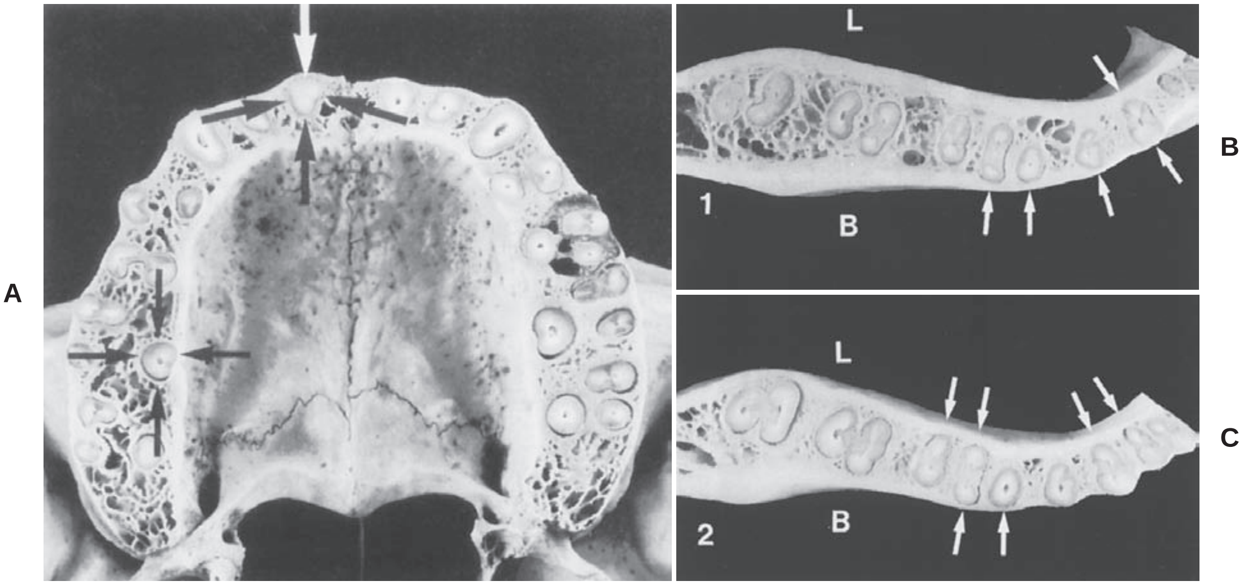


FIGURE 23-6 **A,** Cross section through the maxillary alveolar process at the midroot level of the teeth, showing the extreme thinness of the buccal bone in the maxillary arch. **B,** Cross section through the mandibular alveolar process at the coronal and apical thirds of the roots. The art illustrates the thin labial bone on the mandibular teeth in the crestal two thirds. **C,** Note the thin facial bone over the sockets from which the maxillary teeth were removed. *B* = Buccal; *L* = labial. *(**B,** From Lindhe J:* Textbook of clinical periodontology, *Copenhagen, 1989, Munksgaard.)*

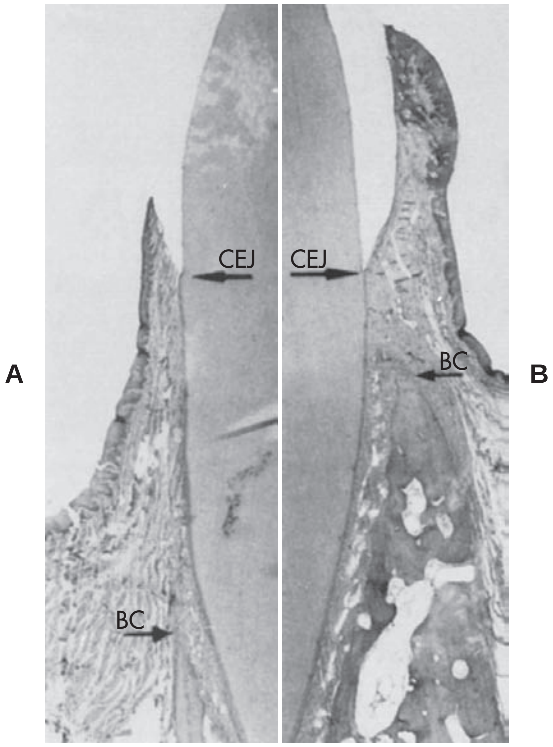


FIGURE 23-7 Histologic specimens demonstrating **(A)** reduced alveolar bone height at an incisor that has been bodily moved in a labial direction and **(B)** normal alveolar bone height at an unmoved control tooth. Note that the connective tissue attachment has been maintained; however, the free gingival tissue on the labially displaced incisor **(A)** has been reduced in height. *BC* = Bone crest; *CEJ* = cementoenamel junction. *(From Lindhe J:* Textbook of clinical periodontology, *Copenhagen, 1989, Munksgaard.)*

quantity of bone support, the point of force application, and the center of rotation come into play to determine stress areas in the periodontal ligament. To prevent tissue damage, one must consider areas of maximal stress that might occur in the periodontal ligament. The risk of bone loss is higher if inflamed connective tissue is located apical to crestal alveolar bone,[41] and certain types of force may aggravate the progression of inflammatory periodontal disease.[42] Periodontal disease in a periodontal ligament under stress has been shown in rats (between M1 and M2), where infectious inflammatory infiltration spreads from the epithelial aspect into the transseptal ligament (Figure 23-11, *A*). These animals showed complete destruction of the transseptal ligament within 28 days.[43]

To prevent aggravated loss of attachment or tissue damage, therefore, determining maximal stress areas, which can occur crestally or in the periodontal ligament, is crucial. Although most tooth movement involves combinations of movements, clinicians tend to view movement more simply in terms of extrusion (eruption), intrusion, tipping, translation, and torque.

Extrusion (Eruption). Extrusion, or eruption, of a tooth or several teeth, along with reduction of the clinical crown height, has been reported to reduce infrabony defects and decrease pocket depth.[44,45] Single-tooth eruption should be distinguished from overbite correction and control of the vertical dimension during routine orthodontic correction. Extrusion of an individual tooth is used specifically for correction of isolated periodontal osseous lesions. Studies have shown that eruption in the presence of gingival inflammation reduces bleeding on probing, decreases pocket depth, and even causes the formation of new bone at the alveolar crest as teeth erupt, with no occlusal factor present and while controls remain unchanged.[46] Eruption or uprighting of molars without scaling and root planing in human patients has been shown to reduce the number of pathogenic bacteria.[47] During clinical treatment, however, inflammation always should be controlled to ensure that the supracrestal connective tissue remains healthy and that the crestal alveolar bone height remains at its original level.

In the double-blind molar uprighting study done at the University of Pennsylvania,[47] bacterial samples were taken from the mesial pockets of molars to be uprighted (experimental tooth) and from the contralateral mesially inclined molar that served as the control in each subject. Indirect immunofluorescence was used to identify *Bacteroides forysthus, B. gingivalis, B. intermedius,* and *Actinobacillus actinomycetemcomitans*. During the study, no scaling, root planing, or subgingival inflammatory control was used. This study revealed that in all experimental sites that showed these microorganisms at the time of bonding, the number had diminished significantly by the end of treatment. However, Hawley bite planes were worn by all patients to disarticulate the molars during molar uprighting. In a similar study of 10 patients over a 12-week period, in which the effects of molar uprighting on the microflora of human adults were assessed using DNA probes, the number of *Bacteroides* pathogens was found to decrease at the experimental site with uprighting.[48]

Eruption of a tooth is the least hazardous type of movement to solve osseous morphologic defects on individual teeth created by periodontal disease or tooth fractures. Extrusion of anterior segments in skeletal openbite patterns with muscular problems has shown shortening of the roots. If teeth have normal bone support or if bone loss has been horizontal (the alveolar crests and the cementoenamel junctions are level), then movement should involve intrusion or extrusion as necessary to correct the orthodontic deformity.

Intrusion. Conflicting evidence has been reported regarding the benefits of intrusion of individual teeth. One study has reported that intrusion of individual teeth did not result in the development of pockets.[49] This same investigator had reported earlier that intrusion in monkeys induced increased new attachment levels after flap operations to excise pocket epithelium and place an experimental notch on the root.[50] In periodontal research,

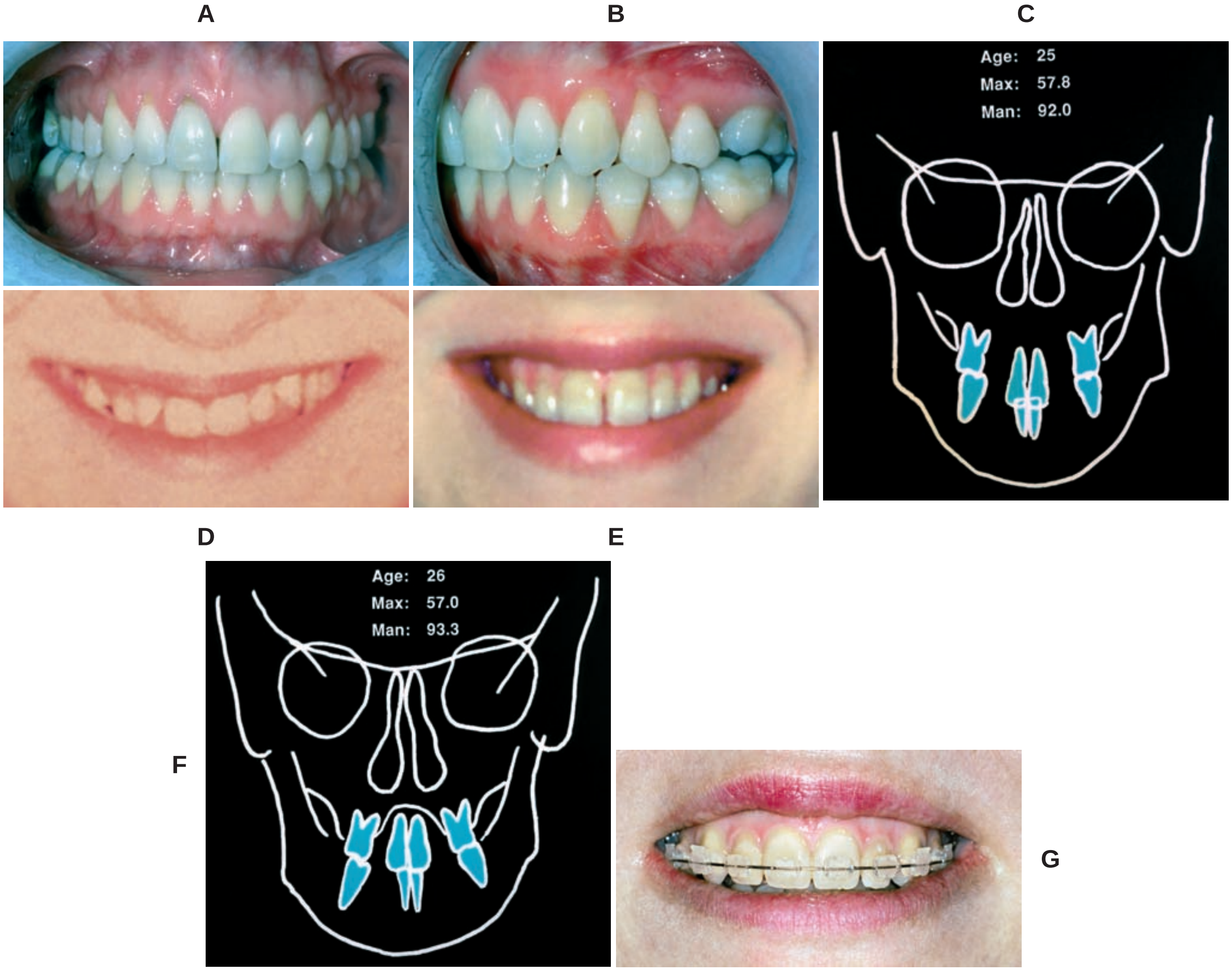


FIGURE 23-8 A case in which orthodontic treatment was done, and the transverse skeletal discrepancy was camouflaged. **A,** Posttreatment right lateral view. The case is unstable and has significant gingival recession in buccal segments and poor dental aesthetics with negative space between the cheeks and the buccal segments. **B,** Gingival recession on the maxillary and mandibular premolars. **C,** The skeletal pattern is normal in the sagittal and vertical dimensions. On the posteroanterior cephalometric tracing, note the maxillary and mandibular widths. The Mx-to-Mx maxillary distance (57.8 mm) and the AG-to-AG mandibular distance (92.0) can be evaluated from the posteroanterior cephalometric radiograph. **D,** A 15-year-old patient with a severe Class III condition and normal transverse skeletal dimension; with a full smile there is no negative space. **E,** Note the large negative spaces in the corners of the buccal segments of a 26-year-old woman with transverse maxillary deficiency and mandibular excess. **F,** Posteroanterior cephalometric tracing. Note the maxillary and mandibular widths. **G,** Negative space is eliminated by surgically assisted rapid palatal expansion performed to correct the transverse skeletal dysplasia. Excess gingiva was removed with the gingival retention procedure at appliance removal.

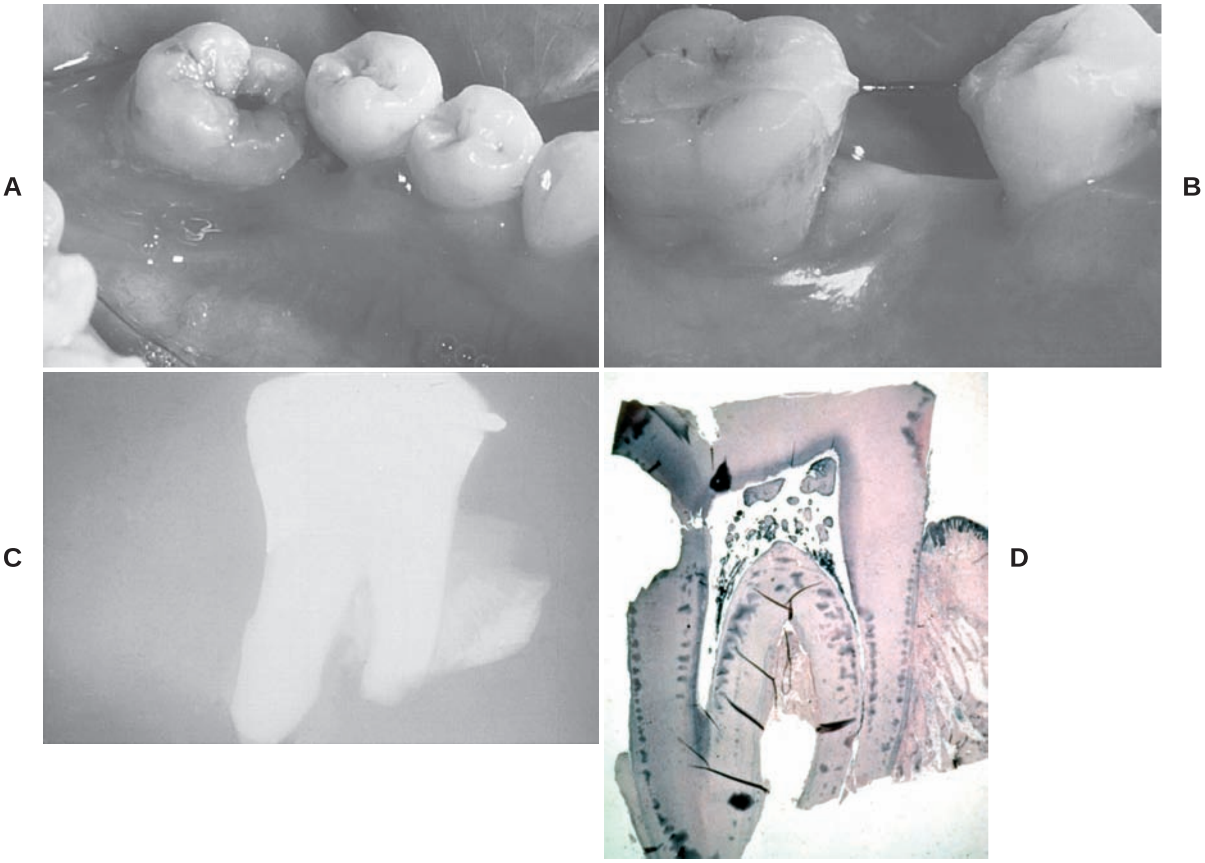


FIGURE 23-9 **A,** Mesially inclined molar before being uprighted. **B,** Reduction of mesial soft tissue pocket depth. The extrusive component of uprighting the molar allows for eversion of the pocket epithelium. **C,** Radiograph of a human clinical case after a tooth has been uprighted. **D,** Histologic slide of the tooth. Note the new bony spicules on the mesial where the alveolar crest has remodeled from the tension of the connective tissue attachment. No reattachment or increase in new attachment is evident. *(**A, B**, From Browns IS: Effect of orthodontic therapy on periodontal defects,* J Periodontol *47:742, 1973;* ***C, D,*** *courtesy I.S. Brown, Philadelphia.)*

dogs and monkeys are well known to show new attachment during normal healing after surgical flap procedures without tooth movement (Figure 23-12), and this has been described.[51] Others have observed that intrusion may result in root resorption, pulpal disturbances, and incomplete root formation in younger individuals.[52] Clinicians have cautioned that intrusion of anterior teeth during leveling of the occlusal plane to correct overbite can deepen infrabony defects (Figure 23-13) on individual teeth.[53] These conflicting reports indicate that intrusion can be a more hazardous type of movement; because the force is concentrated at the apex, root resorption has been a well-known sequela, and light forces have been recommended (see Chapters 5 and 6).

Intrusion has been reported to alter cementoenamel junction and angular crest relationships and to create only epithelial attachment roots; therefore a periodontally susceptible patient is at greater risk of future periodontal breakdown (Figure 23-13, *B, C*). Tooth movement, when properly executed, improves periodontal conditions and is beneficial to periodontal health. Extrusion is much more predictable than intrusion in accomplishing this purpose. Whenever the treatment objective is new connective tissue attachment or periodontal regeneration to restore lost supporting periodontal tissues, guided tissue regeneration (e.g., barrier membranes) is the predictable way to manipulate cells that lead to new attachment. Guided tissue regeneration procedures always should precede orthodontic tooth movement and should be part of the initial therapy before active orthodontic treatment is begun.

Tipping. When a single force is applied to the crown of the tooth, the tooth can rotate around its center of resistance (for an incisor, about the midpoint of the root), and compression (pressure) is increased at the crest and at the root apex (see Chapter 7). In this case, half of the periodontal ligament has the potential to receive high pressure from essentially light force.

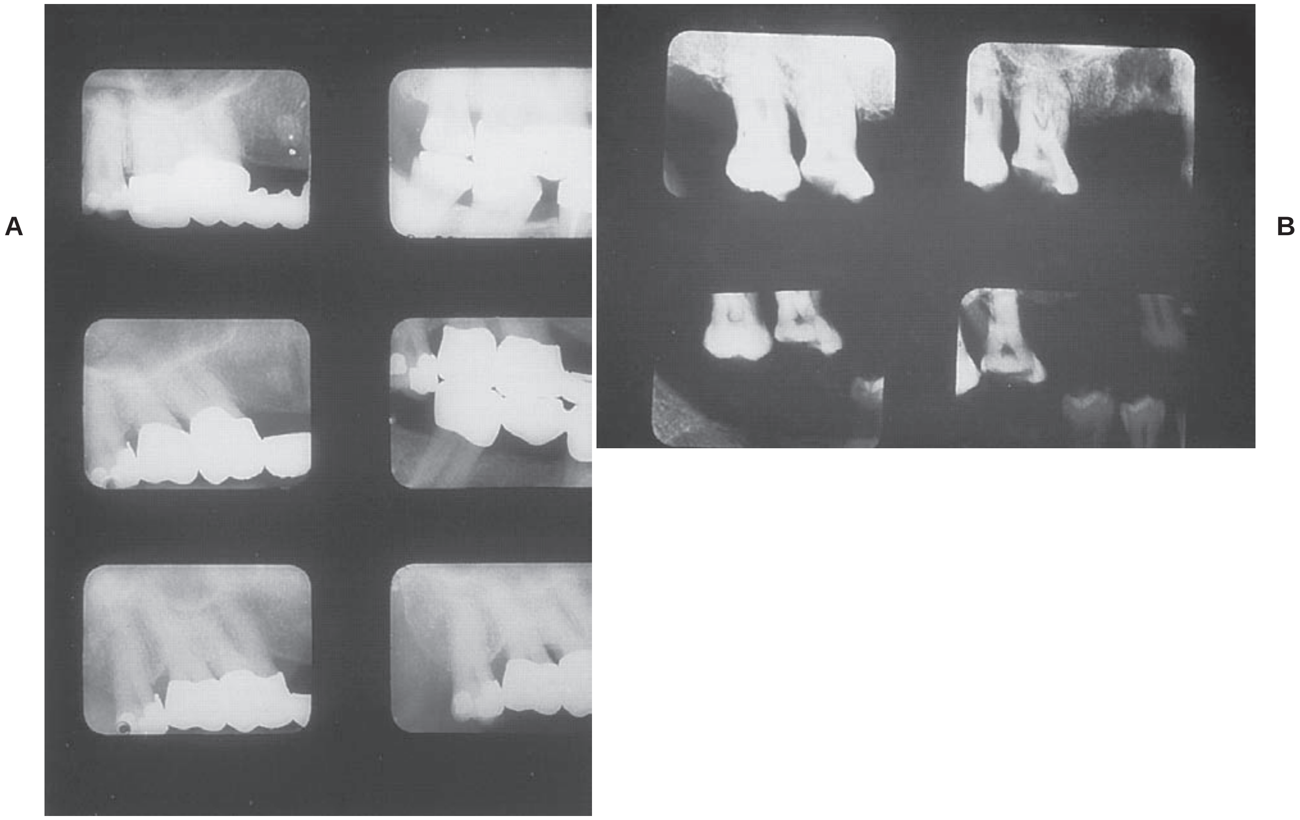


FIGURE 23-10 Periapical films taken over an 18-year span. **A,** The maxillary third molar erupts naturally. The area was kept clean, and the bone followed the tooth. **B,** Radiograph of unopposed tooth erupting in the presence of periodontal disease. The bone does not follow the tooth. *(Courtesy Morton Amsterdam, Philadelphia.)*

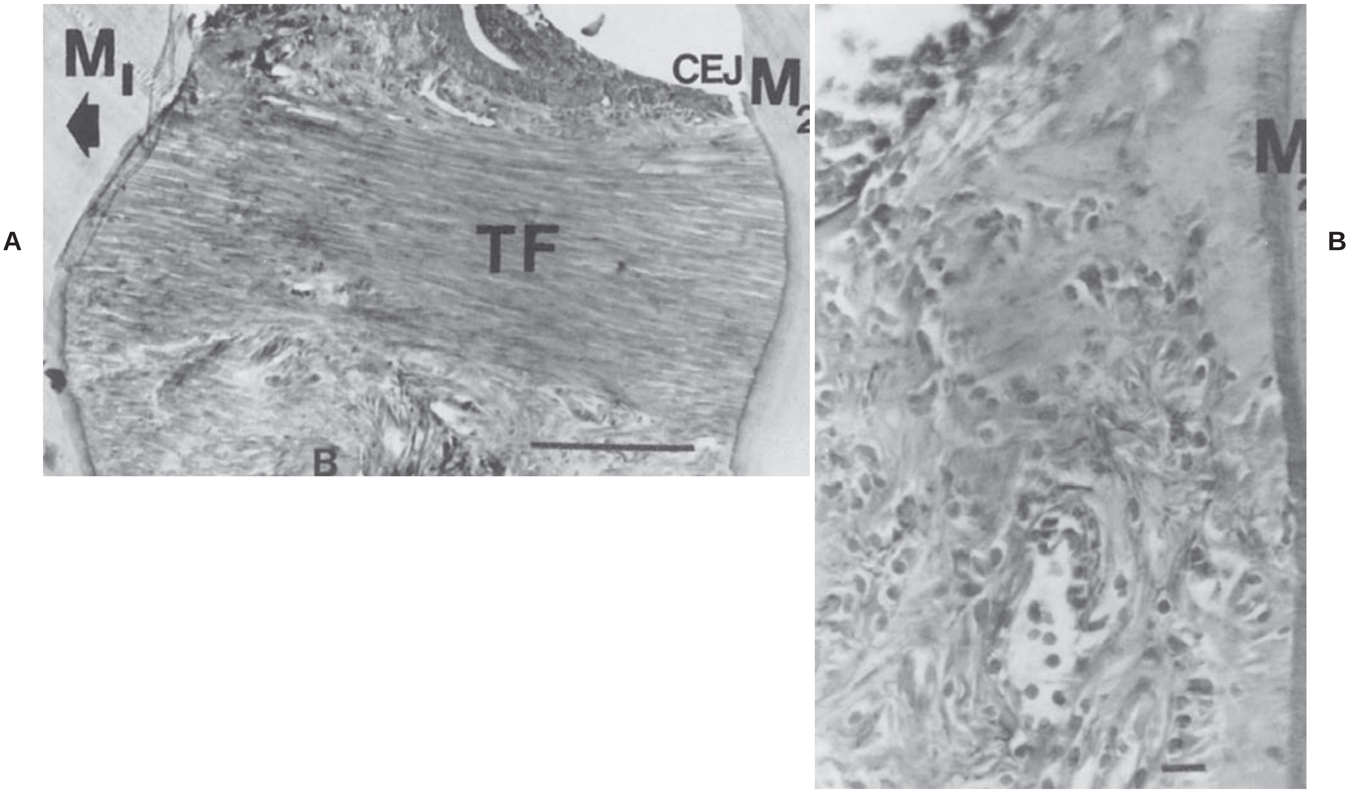


FIGURE 23-11 **A,** Area of tension. The first molar, M_1, moved in the direction indicated by the arrow for 28 days. Stretched transseptal fibers are detached from the alveolar bone crest. **B,** Area of tension mesial to the second molar, M_2. Periodontal disease with inflammatory infiltration and breakdown of transseptal fibers resulting from impaction of food caused by loss of approximal contact. *CEJ* = Cementoenamel junction; *TF* = transseptal fibers. *(From Norton LA, Burstone CJ, editors:* The biology of tooth movement*, Boca Raton, Fla, 1989, CRC Press.)*

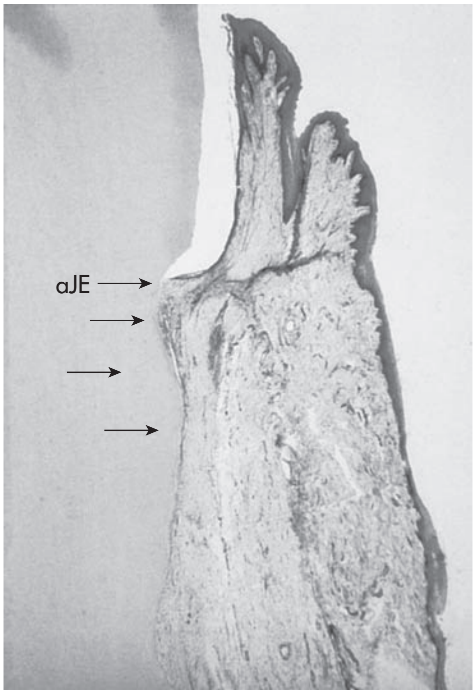


FIGURE 23-12 Normal healing after flap surgery in a dog (without tooth movement). A new connective tissue attachment has formed and extends coronally from the apical border of the notch prepared at the surgically created bone crest to the apical termination of the apical junctional epithelium (aJE). *(Courtesy J Lindhe, Göteborg, Sweden.)*

Experiments in beagles demonstrated that with tipping and intruding movements, forces were capable of causing conversion of a gingival lesion to a lesion associated with attachment loss.[53a] In tipping movements, the force should be light and the area should be kept clean to prevent the formation of angular bony defects.

Bodily Movement into a Defect. Movement into infrabony defects has been suggested to result in healing and regeneration of the attachment apparatus.[54] In addition, periodontists have believed that if a wide osseous defect is adjacent to a tooth and the tooth were moved to narrow the defect, better healing potential may be possible. Unfortunately, a more recent study has shown that if infrabony defects are created in the lower incisor area of rhesus monkeys (undergoing good plaque control) and the tooth then is moved into and through the original defect, a long epithelial attachment to the roots is created, with no new attachment apparent.[55] The results, however, indicated that even though movement into infrabony periodontal defects did not result in regeneration of attachment, no further loss of connective tissue attachment occurred.

The most recent study performed in four beagles found that angular bony defects were created and plaque was allowed to accumulate. Teeth were translated into inflamed, infrabony pockets, and additional attachment loss occurred on the teeth moved into the infrabony pockets.[56] Therefore, the conclusion was that bodily tooth movement may increase the rate of destruction of the connective tissue attachment of teeth with inflamed, infrabony pockets.

At the University of Pennsylvania, teeth have been moved into defects, with the patients' contralateral side serving as the control (Figure 23-14). Radiographs revealed that loss of attachment occurred when a tooth was moved into a defect in an edentulous area (Figure 23-14, *D, E*). The tooth can move away from a defect and, with sufficient eruption, a bony defect can be reduced or eliminated; this usually is the treatment of choice to improve osseous architecture.

A study involving closure of edentulous spaces in the mandible was done on a group of patients ranging in age from 11 to 17 years, and the results were compared with those from a group of patients aged 23 to 46 years.[57] The results indicated that the older adults had more loss of crestal bone and greater root resorption than the younger patients.

MUCOGINGIVAL CONSIDERATIONS

During tooth movement, the periodontal tissues should maintain a stable relationship around the cervical area of the tooth. An adequate amount of attached gingiva is necessary for gingival health and to allow appliances (functional or orthopedic) to deliver orthodontic treatment without causing bone loss and gingival recession. Clinical experience and animal studies clearly have established that more pronounced, clinically recognizable inflammation occurs in regions with a lack of attached gingiva (Figure 23-15, *A*) than in areas with a wider zone of attached gingiva (Figure 23-15, *B*). Histologically, the teeth lacking gingiva were thinner in the buccolingual dimension than were those with a wide zone of attached gingiva; however, investigators reported that inflammatory cell infiltrate and its apical extrusion (degree of inflammation) were similar.[58,59] Two studies have indicated that as teeth are moved labially and tension is created on the marginal tissue, the thickness of the gingival tissue on the pressure side becomes important.[60] With labial bodily movement, incisors showed apical displacement of the gingival margin, but no loss of connective tissue attachment was apparent where there were no signs of inflammation. Where inflammation was present, loss of connective tissue attachment occurred.[39] Therefore if the tooth movement is expected to result in a reduction of soft tissue thickness and an alveolar bone dehiscence may have occurred in the presence of inflammation, gingival recession is a risk. Obviously, all orthodontic cases involve gingival inflammation, and bodily facial movement can predispose the patient to gingival recession; a gingival graft can be used to prevent this.

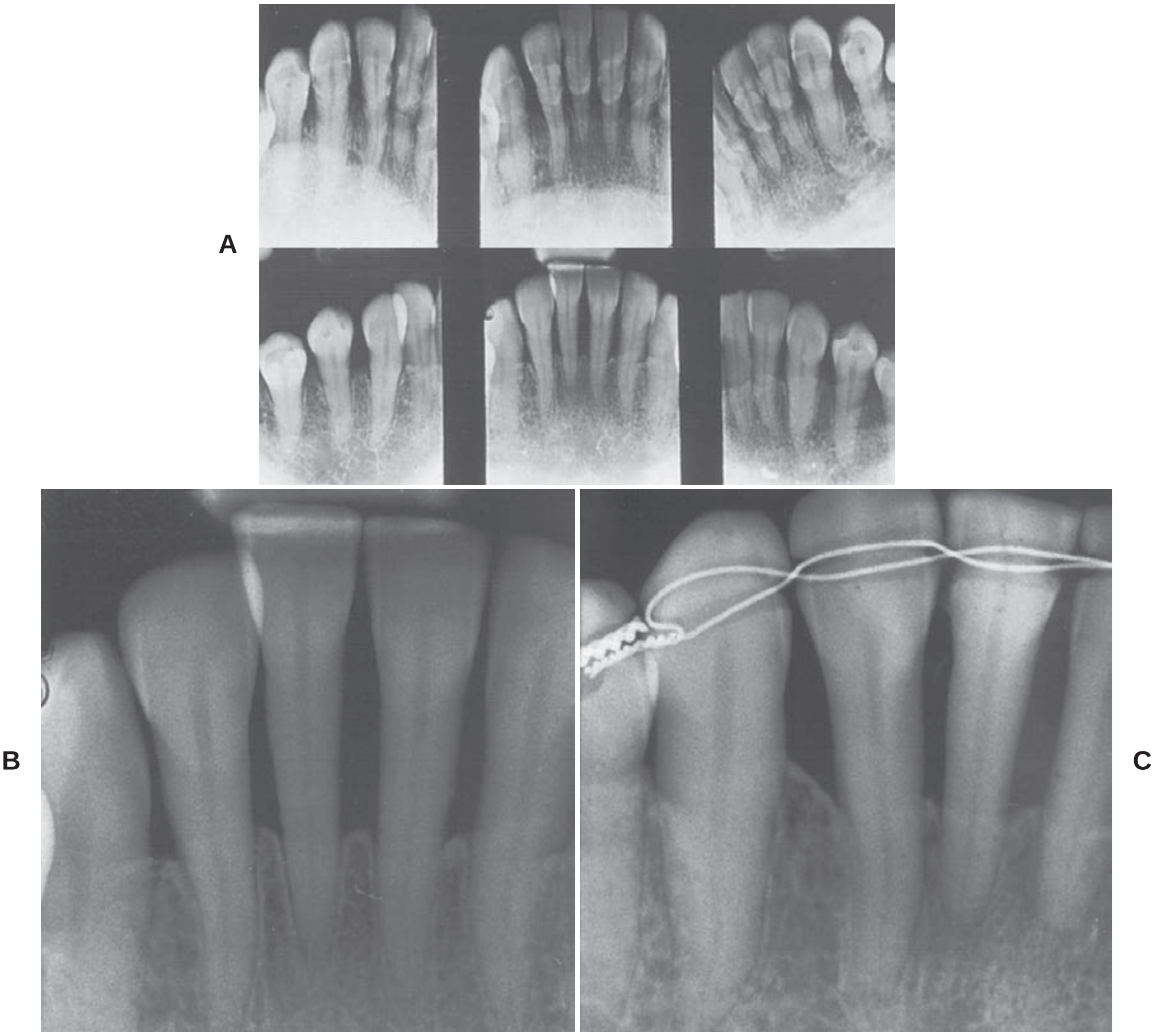


FIGURE 23-13 **A,** Radiographs of lower anterior teeth showing loss of bone before scaling. Lower radiographs were taken after scaling. Note that bone loss is horizontal (level alveolar crests) between the canine and incisor groups. The ideal way to reduce the overbite would have been to reduce the crowns with a high-speed bur and improve the crown-to-root ratio, keeping the bone level between adjacent teeth. Instead, the teeth were banded according to the incisal edge and were intruded. **B,** Preorthodontic periapical radiograph of lower anterior teeth before intrusion. Note the level alveolar crest between the canine and the lateral incisors. **C,** Periapical radiograph of lower anterior area after intrusion. Note that the cementoenamel junction is no longer level between the canine and the lateral incisors; however, a large angular crest has been created between those two incisors. An angular crest has been described as a predilected site for periodontal breakdown. *(From Marks MH, Corn H, editors:* Atlas of adult orthodontics*, Philadelphia, 1989, Lea & Febiger.)*

The free gingival graft is the most versatile, widely used, and predictable procedure for gingival augmentation.[39] When free gingival graft is performed before recession occurs, it is considered to be less traumatic and highly predictable, and it prevents recession during orthodontics. However, many periodontists still believe that with younger patients, a wait-and-see attitude is acceptable because so many predictable ways of correcting recession have become available. Root exposure is most likely to be progressive in a younger patient because labial bone loss may be impossible to correct; it is essential to prevent labial bone loss. For this reason, clinical judgment and animal studies support the need to create a thicker gingiva that can withstand the inflammatory insult better during tooth movement.

Thin, delicate tissue is far more prone to exhibit recession during orthodontics than is normal or thick tissue. If a minimal zone of attached gingiva or thin tissue exists (Figure 23-16), particularly on abutment teeth, a free gingival graft that enhances the type of tissue around the tooth helps control inflammation; this should be done before orthodontic movement is begun. The orthodontist also should evaluate differences in alveolar housing. That a thin, soft tissue is associated with a thin

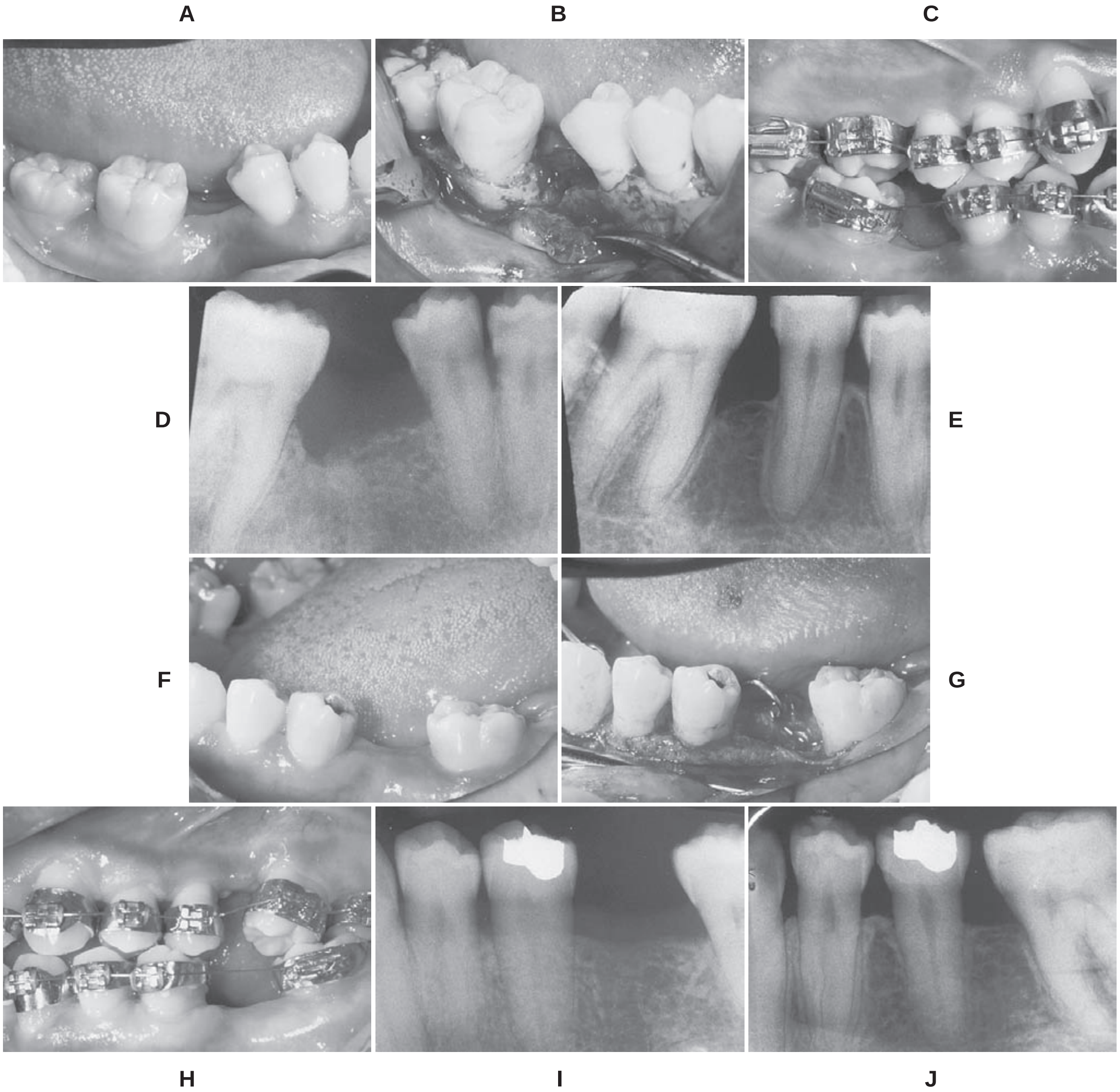


FIGURE 23-14 **A,** A 37-year-old man with bilaterally missing mandibular first molars. Lower right preoperative (test side) view of side with defect in edentulous area. **B,** Lower right edentulous ridge area with tissue reflected. Note the defect mesial to the second molar. **C,** Appliance placement on the right side to begin space closure. **D,** Preorthodontic periapical radiograph. Note the mesial attachment level radiographically. **E,** Postorthodontic periapical radiograph. Note the evidence of bone loss on the mesial of the second molar during space closure. **F,** Lower left preorthodontic view of the side without a vertical defect in the ridge. **G,** Tissue reflected in lower left (control side). Note that no defect is seen in the osseous ridge mesial to the second molar. **H,** Appliance placement on the left side to begin space closure. **I,** Periapical radiograph of the lower left side before space closure. Note the mesial attachment on the second molar. **J,** Periapical radiograph after space closure. No radiographic evidence of bone loss appears on the mesial of the second molar on the control side.

labiolingual osseous support is not necessarily true. All combinations are seen, such as thick, soft tissue with a thin labial plate of bone. To change the labial osseous thickness (especially the thin type) that is characteristic of the individual patient is difficult; however, to improve the soft tissue with a free graft is not difficult or traumatic. Obviously the decision concerning prophylactic periodontal procedures must be made with consideration, among other things, for growth and development, tooth position, type and direction of anticipated tooth

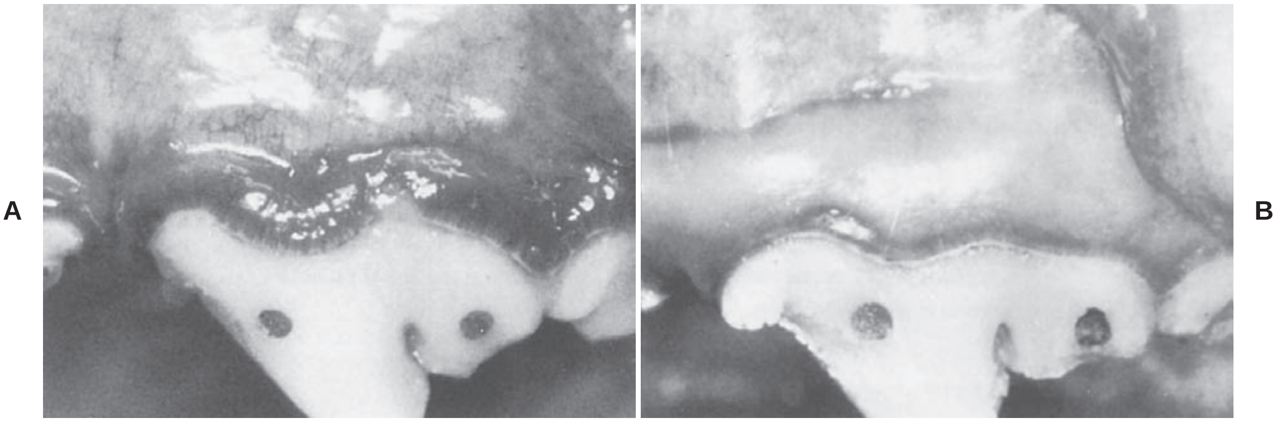


FIGURE 23-15 Teeth in a dog after 40 days of plaque accumulation. The clinical signs of inflammation are more pronounced at the site with the narrow band of gingiva, **A,** than at the site with a wide zone of attached gingiva, **B.** The vascular system is believed to have been more readily visible in its thinner units that lack gingiva. *(From Lindhe J:* Textbook of clinical periodontology, *Copenhagen, 1989, Munksgaard.)*

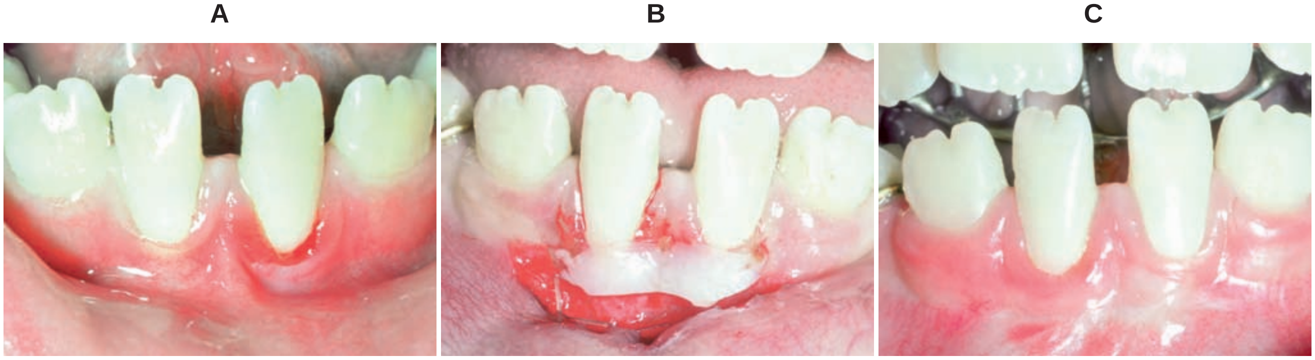


FIGURE 23-16 **A**, Inadequate attached gingiva on the lower central incisors of an 8-year-old girl. The signs of inflammation are pronounced, especially on the left central side; a free graft should be placed before early treatment protocols are begun. **B,** Donor tissue from the palate in place. **C,** Postoperative result before treatment was begun.

movement, oral physiotherapy, integrity of the mucogingival junction, tissue type, inflammation, muscle pull, frenum attachment, mucogingival and osseous defects, anticipated tissue changes, and profile considerations (Box 23-1).

Critical evaluation of the periodontium before orthodontic treatment begins can prevent, minimize, or at least avoid aggravation of an existing periodontal condition. Other areas that frequently involve conflicting periodontal management are frenum considerations, gingival hyperplasia, mouth breathing, and ectopically positioned teeth.

BOX 23-1 Diagnostic Considerations in Case Selection for Grafting before Orthodontic Treatment

- Growth and development
- Tooth position
- Oral physiotherapy
- Types of hard and soft tissue
- Inflammation
- Integrity of the mucogingival junction
- Mucogingival and osseous defects
- Type and direction of anticipated tooth movement
- Tissue changes associated with tooth movement
- Profile considerations
- Mechanotherapy to be used
- Patient cooperation

FRENUM CONSIDERATIONS, GINGIVAL HYPERPLASIA, GINGIVAL RETENTION, AND MOUTH BREATHING

Mandibular Midline Frenum

When a frenum is associated with a mucogingival problem, it most often relates to an inadequate zone of attached gingiva. For this reason, the use of frenectomy to correct mucogingival problems is considered obsolete. The high frenum insertion contributes to movement of the marginal gingiva where the keratinized tissue has been lost or detached or where mechanical trauma exists. This problem is most prevalent in the lower anterior area.

Maxillary Midline Frenum

In the past, frenectomy has been recommended in the maxillary midline for young children on the ground that the midline diastema is caused by the maxillary labial frenum. Many believe that this frenum prevents mesial migration of the maxillary central incisors and that it should be removed before orthodontic therapy is begun. Others have suggested that removal of the frenum allows the space to be closed more easily orthodontically. However, the practitioner must remember that a physiologic space normally is present between the maxillary central incisors until eruption of the canines in the adolescent dentition. In addition, a frenectomy may cause scar tissue that could prevent orthodontic space closure. With large diastemas (6 to 8 mm) in the early transitional dentition, a frenectomy usually is recommended to facilitate space closure, regain space at the midline, and prevent ectopic eruption of the lateral incisors or canines. These interceptive early treatment problems require complete orthodontic supervision, usually additional mechanotherapy, and several stages of treatment.

A U- or V-shaped radiographic appearance of the interproximal bone between the maxillary central incisors is a diagnostic key to the persistent midline diastema (Figure 23-17). This radiograph of the mature midline suture with firm teeth before orthodontic treatment indicates that relapse will follow even excellent orthodontic treatment (i.e., no occlusal discrepancies, muscular habits, or problems; no tooth-size discrepancies; and ideal axial inclinations, overbite, and overjet). The patient should be informed before orthodontic treatment of the need for indefinite retention with bonding of the central incisors after treatment to prevent return of the maxillary midline diastema.

Generally, surgical removal of a maxillary labial frenum should be delayed until after orthodontic treatment unless the tissue prevents space closure or becomes painful and traumatized (Figure 23-18). Removal may be indicated after treatment to change irreversible hyperplastic tissue to normal gingival form and to enhance posttreatment stability. This is particularly helpful on incisors during phase I of early treatment problems.

Gingival Hyperplasia

Mild gingival changes associated with orthodontic appliances seem to be transitory, and the periodontal tissues sustain little permanent damage.[61] Gingival hyperplasia usually resolves itself or responds to plaque removal, curettage, or both. Should the gingival tissue or enlargement interfere with tooth movement, however, it must be removed surgically. Otherwise, waiting until the

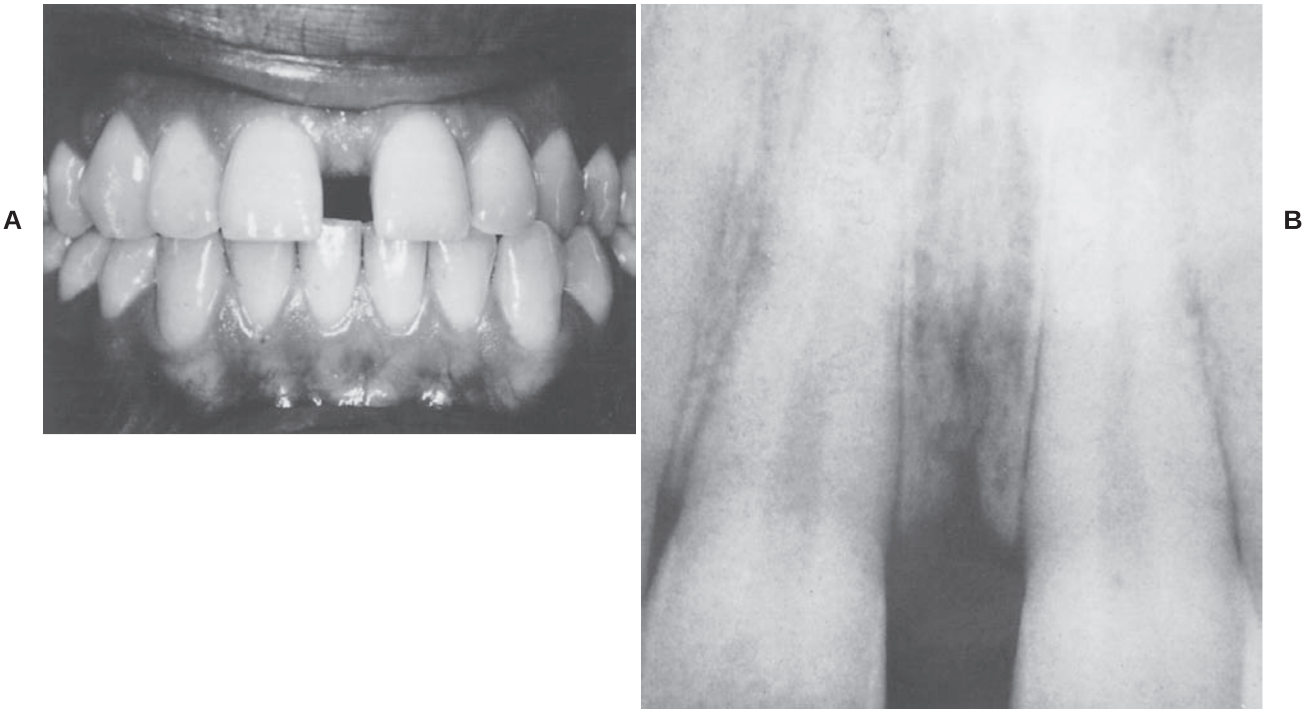


FIGURE 23-17 **A,** Clinical appearance of a persistent midline diastema in a 20-year-old woman. **B,** Radiographic appearance of midline interdental bone before orthodontic treatment, showing a V-shaped suture, which is the diagnostic key to potential relapse.

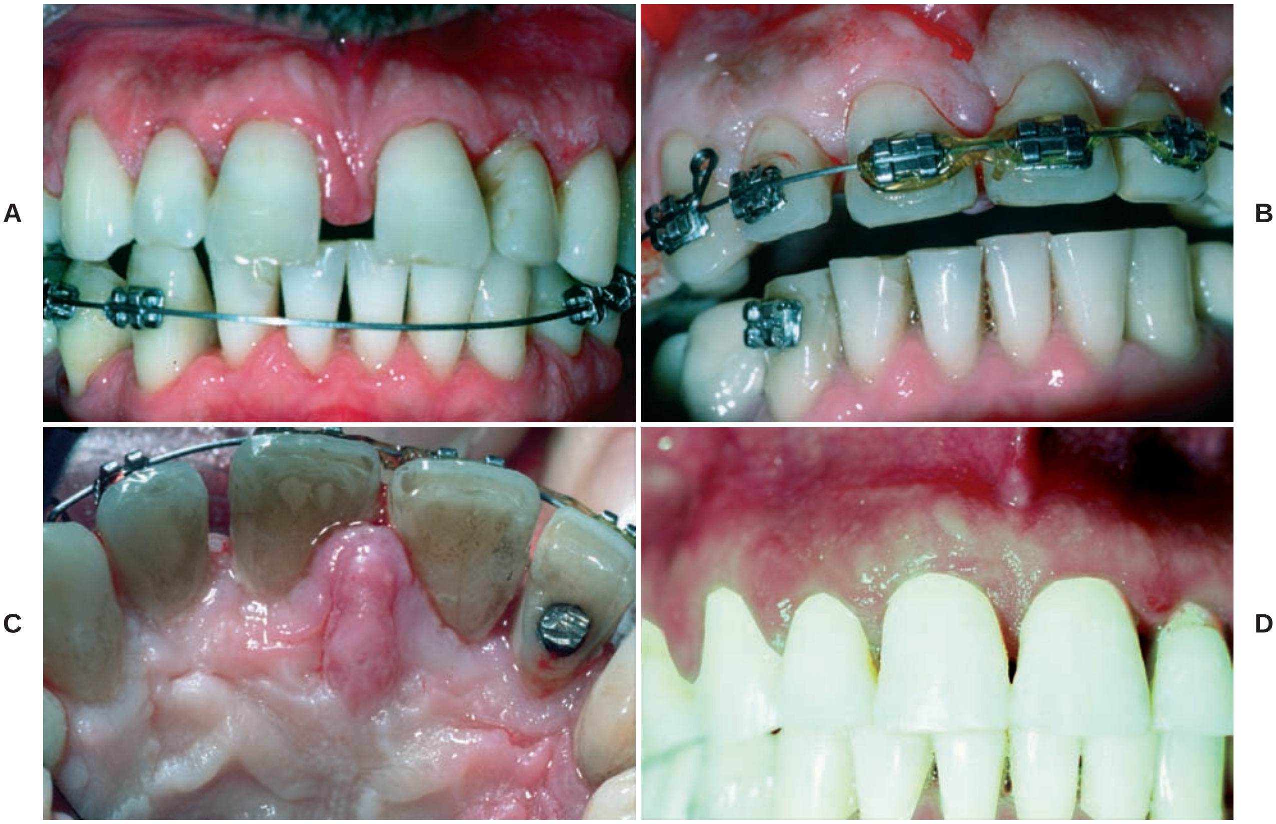


FIGURE 23-18 **A,** Preorthodontic diastema of a 40-year-old man with significant periodontal disease and loss of posterior support**. B, C,** During closure of the midline diastema, the soft tissue became enlarged and sore and prevented complete space closure. A frenectomy was performed to remove the frenum, which allowed completion of tooth movement. **D,** Midline area after completion of tooth movement and reestablishment of posterior support.

appliances are removed to correct surgically abnormal gingival form[62] and using the procedure to enhance post-treatment stability are preferable.

Gingival Retention and Aesthetic Considerations

Often tissue shows an exaggerated response to local factors, and gingival reflection with internal bevel incision (gingivectomy) can be done to promote stability and achieve optimal aesthetics and gingival topography (see Chapter 23). In adults with altered passive eruption, the gingival tissue fails to recede, and the patient thinks that the teeth are short (Figure 23-19). Many such patients have thick buccal alveolar bone that must be thinned by minor osteoplasty; if necessary, the orthodontist should establish a normal 1.5-mm relationship between the osseous crest and the cementoenamel junction. This prevents the return of the tissue incisally on the anatomic crown during healing. The orthodontist should not do internal bevel gingivectomy and gingival reflection procedures on the labial aspect of anterior teeth that have thin gingival tissue. Also, the orthodontist should reflect tissue on bell-shaped anterior teeth only on the lingual or palatal aspect. The interdental tissue in these two instances may not heal back to the level of the contact points, creating an unaesthetic result. Spaces below the contact points are disturbing to the patient.

Fiberotomy

Fiberotomy[63,64] should be done after any preorthodontically rotated teeth have been corrected, especially maxillary and mandibular anterior teeth (e.g., maxillary lateral incisors with Class II, Division 2 problems). The procedure should be done before debonding after mild overcorrection (3 to 5 degrees). The overcorrection is removed 1 week after the surgical procedure and before impressions for retainers are taken (Figure 23-20). Internal bevel gingivectomy or labiolingual flap reflections with interproximal sutures (see Chapter 23) enhance alignment and reduce labiolingual and vertical dental relapse. These procedures should be done before fixed appliances are removed.

Mouth Breathing

A significant problem in orthodontic patients is the added periodontal insult of mouth breathing. The drying effect on the exposed tissue in susceptible patients is

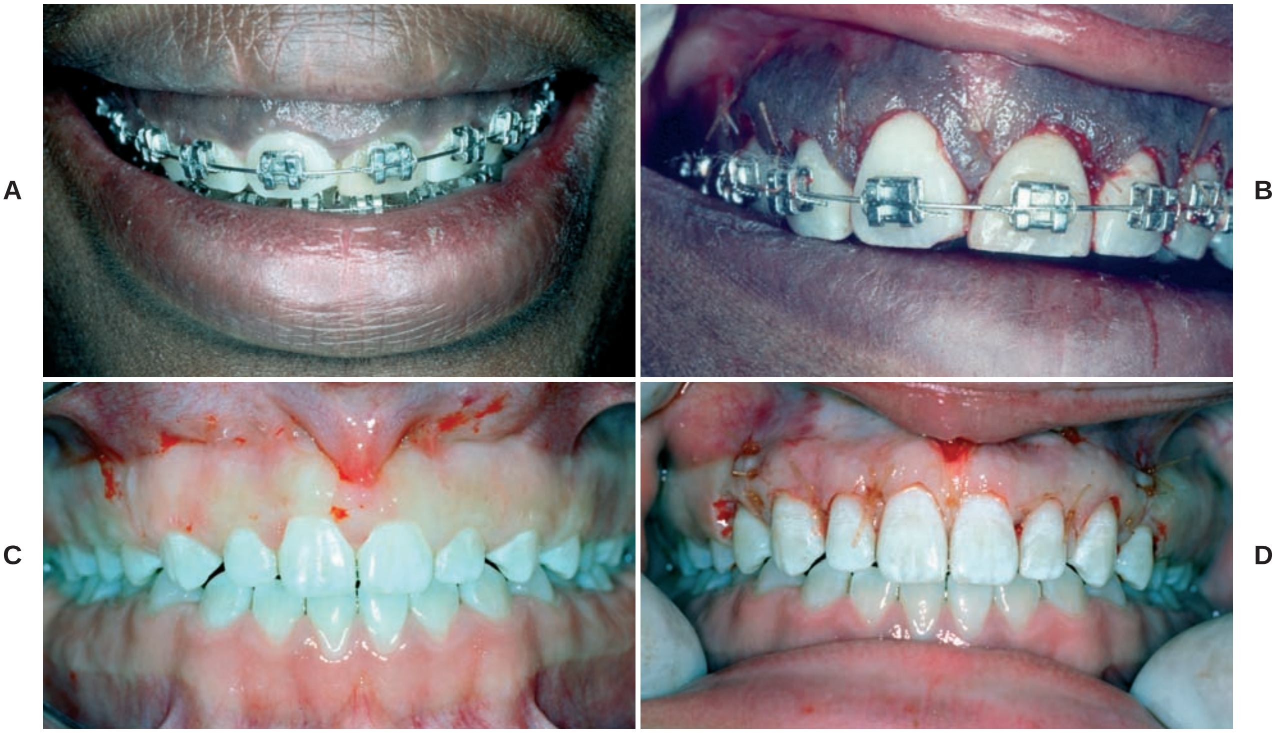


FIGURE 23-19 **A,** A 37-year-old woman who complained of short teeth. The woman has a normal vertical dimension and upper lip length. **B,** Note the normal-sized anatomic crowns at the time an internal bevel gingivectomy was performed for aesthetics and stability. **C**, A 14-year-old girl with short clinical crowns. **D**, After gingival tissue removal.

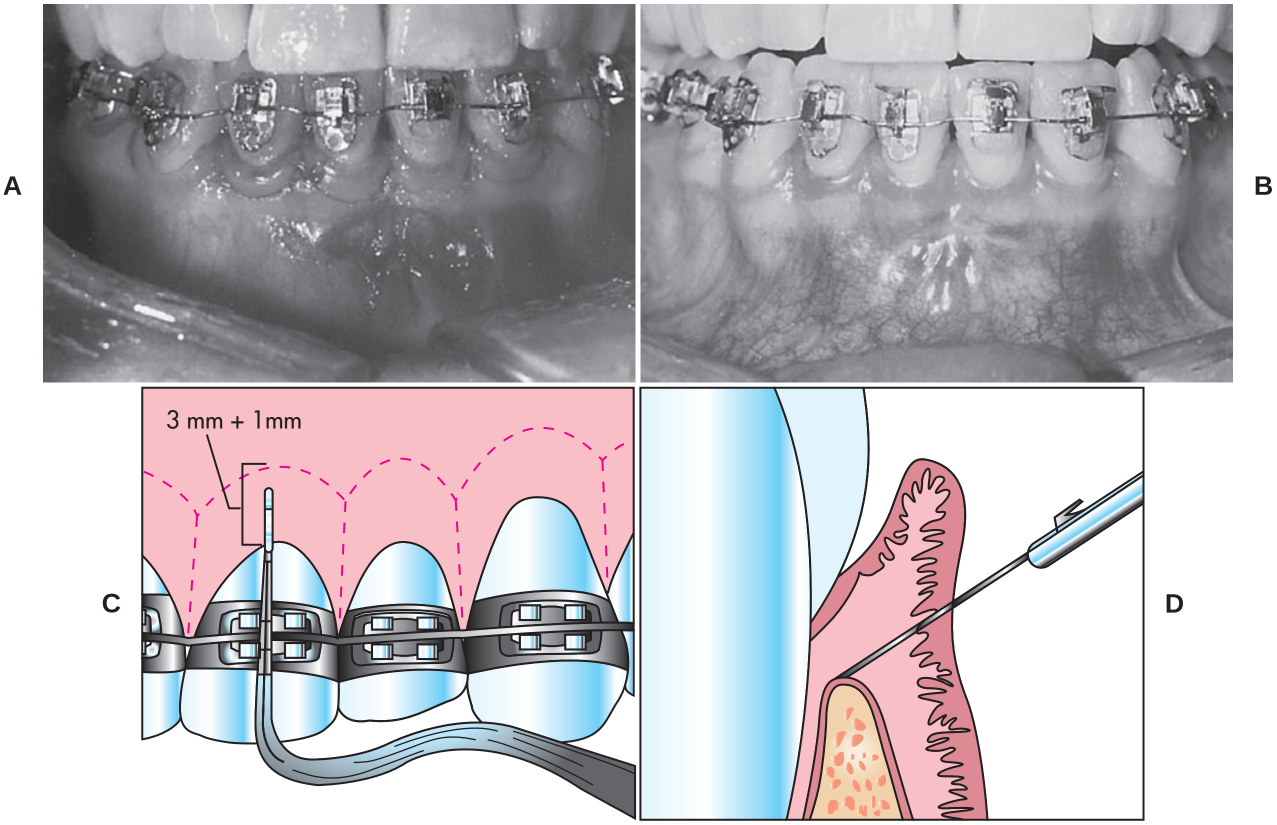


FIGURE 23-20 **A,** Mild overcorrections have been done for the mandibular incisors. Sounding-type incisions are made through the incisal papilla to bone and are angled toward the tooth. The interproximal incisions are joined labially in an attempt to sound out the osseous crest. Incisions are made on the lingual aspects as well. In this case a mandibular frenum was released so that the tissue would not be retracted on the labial aspect of the central incisors. **B,** Two weeks after surgery; overcorrections will be removed. **C,** Representation of probing to establish bleeding points. **D,** Diagram of sounding incision made at a 45-degree angle to the long axis of the tooth. *(From Ahrens DG et al: An approach to rotational relapse,* Am J Orthod *80:83, 1981. With permission from the American Association of Orthodontists.)*

associated with enlarged, erythematous labial gingivae, particularly in the maxillary and mandibular anterior regions. With a short upper lip, a demarcation line usually can be seen where the lip contacts the labial tissue (Figure 23-21). The mouth breather usually has dry, cracked lips as well. Although orthodontic retraction of anterior segments may help provide a better lip seal, extraoral appliances and lip bumpers exacerbate the problem and even may cause mouth breathing in a normal patient. A patient who shows symptoms of an inability to breathe properly (tongue posture; enlarged adenoid tissue; narrow, high palatal vault; allergies) should be referred for evaluation for nasal obstruction and adenoid tissue. Although the plaque index is not significantly higher in mouth breathers, an increase in the gingival index has been reported.[65] This increased inflammation should be reduced to a minimum before fixed appliances are placed, and this usually is accomplished by scaling and curettage.

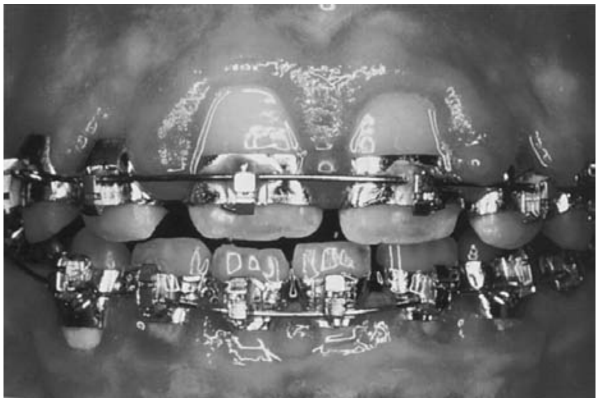


FIGURE 23-21 Exaggerated response to mouth breathing. Note the lip line over the central incisors, where the lip covers the labial gingiva. Enlarged gingival tissue harbors dentobacterial plaque, and the deeper pseudo-pocket acts as a reservoir for retention of subgingival plaque.

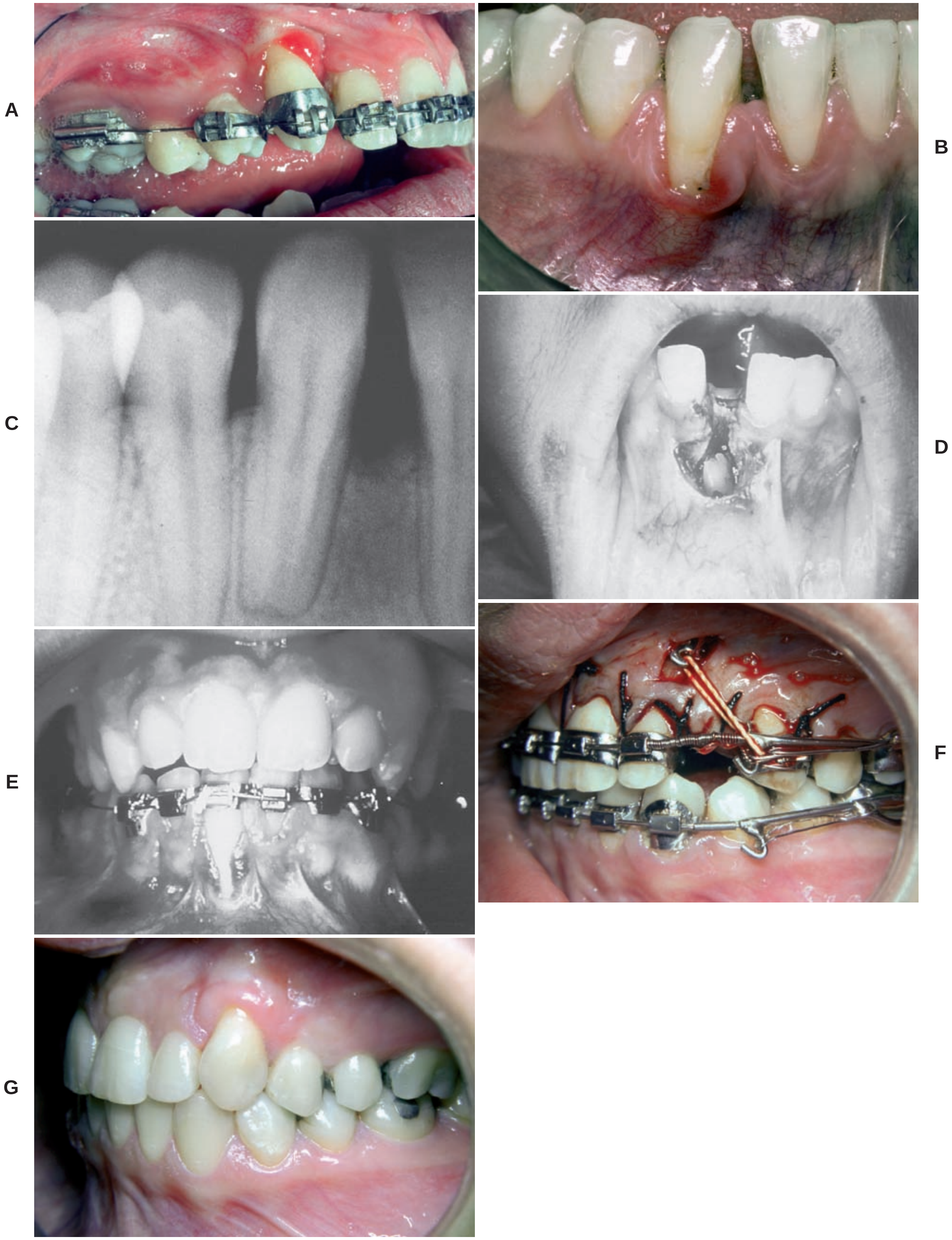
Considerations with Ectopically Positioned and Unerupted Teeth

Many orthodontic patients have teeth that have not penetrated the oral mucosa or that will not erupt. Certain teeth demonstrate eruption that has been delayed significantly beyond the time when normal dental eruption for a particular patient should have occurred. Clinical orthodontists who have treated cases involving unerupted teeth have faced the problems of devitalization, reexposure or reuncovering of a tooth, ankylosis, external root resorption, and injury to adjacent teeth when an unerupted tooth has been surgically uncovered from the wrong side of the alveolar ridge. The marginal bone loss, gingival recession, and sensitivity problems that occur after the roots have been exposed are complications that invariably result in prolonged treatment time, aesthetic deformities, and in many cases, loss of teeth (Figure 23-22, *A–E*). Most of these problems (i.e., reexposure, gingival recession, and bone loss) can be prevented. Proper management of the periodontal tissues is crucial in preventing loss of attachment. For example, one should not use electrosurgery or lasers to uncover teeth. These techniques have attracted considerable attention recently, but they should be used strictly to remove the overlying tissue; excision of the surrounding tissue on the unerupted tooth leaves inadequate keratinized tissue.

Vermette et al.[66] found no difference in periodontal attachment levels between control teeth and teeth uncovered by an apically repositioned flap or a closed surgical technique. However, they reported that teeth uncovered by apically repositioned grafts had more gingival scarring, were less aesthetic, and experienced intrusive relapse more often than did a group of teeth subject to closed eruption or flap replacement. Reflecting a surgical flap, bonding an attachment with a chain, and suturing the flap over the crown always prolongs the treatment time, requires additional surgical procedures, diminishes control of tooth movement, and may cause adverse periodontal responses (Figure 23-22, *F, G*). Localization and the exact position of the tooth must be known before the tooth is uncovered surgically. Palpation, evaluation of the teeth in the arch, panoramic radiographs, periapical views, and occlusal or cephalometric evidence can be helpful.

Labial impactions should not be uncovered and should have a free gingival graft placed on them; free gingival grafts do not survive on enamel.

FIGURE 23-22 **A,** A typical aesthetic and recession problem on a maxillary canine that was surgically uncovered without keratinized tissue being placed on the tooth. **B**, Clinical appearance of a previously unerupted and surgically uncovered mandibular canine. Note the absence of attached gingiva and the gingival recession; the tooth is an aesthetic concern to the patient. **C,** A periapical radiograph reveals marginal bone loss of one third of the alveolar support and root blunting. These complications could have been prevented. **D,** Surgical uncovering involved extraction of the primary tooth and removal of all overlying soft and hard tissue. The surgery did not provide for attached gingiva over the labial of the tooth. **E,** An undesirable response, with recession and loss of attachment as the tooth is guided into the arch. **F,** The maxillary canine was uncovered, an attachment was placed, and the flap was sutured back into place. An elastic was used, with the objective of guiding the tooth into the zone of keratinized tissue. **G,** When a tooth is covered over with soft tissue, it is difficult to guide into the zone of keratinized tissue. Note the root exposure and recession after the tooth has been positioned in the arch with a flap replacement procedure.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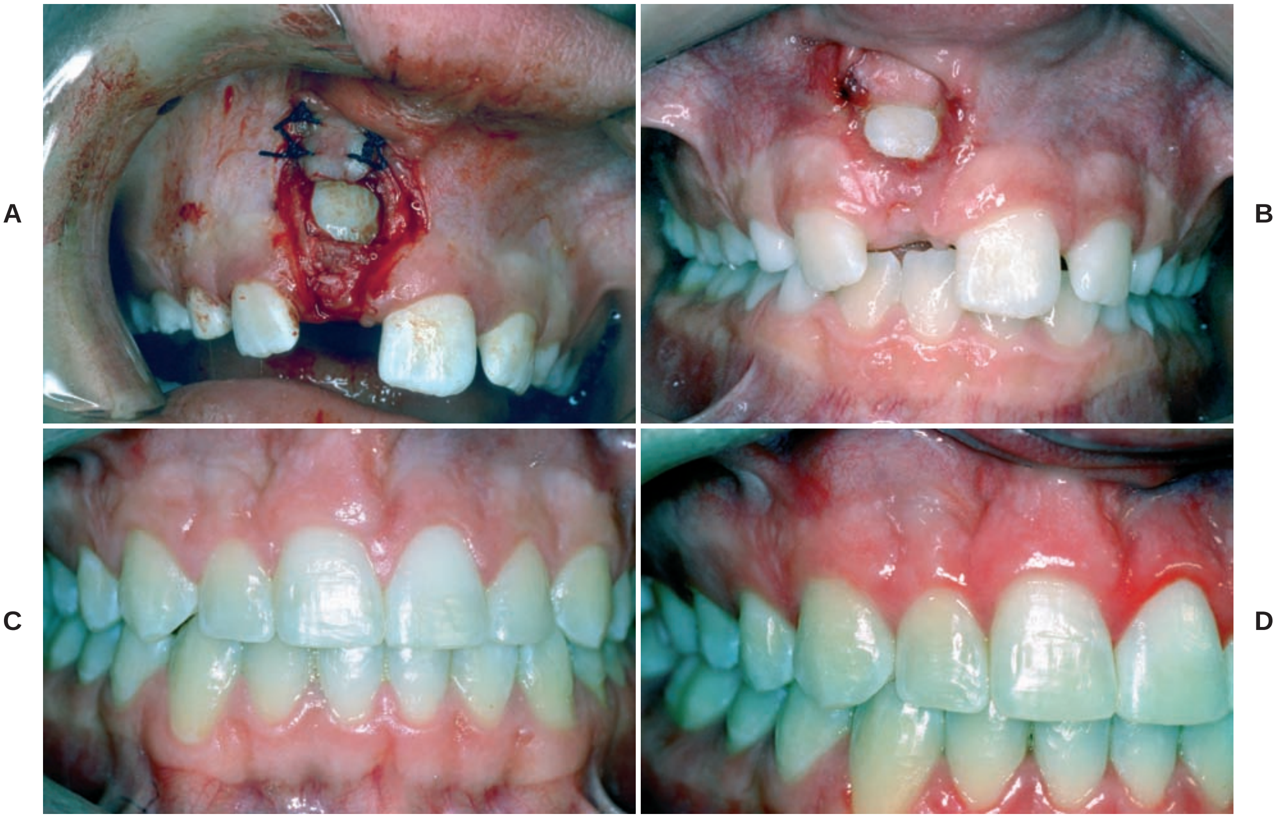

FIGURE 23-23 **A,** A right central incisor was uncovered surgically, and an apically positioned partial-thickness pedicle graft was placed on the cervical area of the anatomic crown. **B,** Several months later. Note that normal eruption has occurred without the use of an appliance. **C,** From the anterior view several years after orthodontic treatment, the gingiva has the same appearance on both central incisors. Detecting that the tooth was grafted is impossible, and normal periodontal support is present. **D,** Right lateral view of the incisor 10 years after surgery.

Surgical Technique. The preferred surgical procedure is primarily an apically or laterally positioned pedicle graft[67] (Figure 23-23). The maxillary incisors can be done nicely from an orthodontic standpoint. When uncovering a tooth, the orthodontist should create a space in the arch before uncovering the tooth if the tooth is on the labial aspect of the arch. The edentulous space created in the arch provides a tissue area to act as a donor site so that an adequate zone of attached gingiva can be taken for the partial thickness of the apically or laterally positioned graft. If space is unavailable between the teeth in the arch, the orthodontist may place a free graft at the mucogingival junction and convert it into a pedicle graft to be placed on the unerupted tooth. Whenever the tissue for a particular patient is so thin that it cannot be dissected away as a partial-thickness graft, one can place a free graft at the mucogingival junction. Grafts should be partial thickness; the orthodontist should express this preference to the oral surgeon because full-thickness grafts are thick and unaesthetic.

Large dental follicles often occur, especially on maxillary canines in 9- or 10-year-olds, before the teeth have erupted from the palate. When these enlarged dental follicles are resorbing hard tooth structure in the arch (i.e., the roots of teeth), they must be uncovered (Figure 23-24). Even though the follicles may not have more than 50% root formation at that point, the orthodontist should uncover the canine and place a bonded attachment. The orthodontist should move the canine into contact with the palatal mucosa, take the attachment off, and allow the root to continue to develop on the canine. If the canine is not uncovered and brought into contact with the oral cavity, the enlarged follicle usually continues to resorb the roots of the incisor teeth. If the palatal tissue is allowed to recover, it begins to resorb the tooth structure again.

The question often arises whether a tooth will erupt into the arch. The real key is the incisal edge; if the incisal edge is headed away from the occlusal plane or if the tooth is upside down, it will not erupt into the oral cavity. If a tooth is erupting slowly or if it is holding up treatment time, it should be surgically uncovered and orthodontically positioned into the arch. The most difficult canine is the canine that erupts between the roots of a premolar, particularly a maxillary first premolar with a bifurcated root (Figure 23-25). The orthodontist should evaluate the periapical radiograph closely for this type of premolar root form. When the canine erupts and

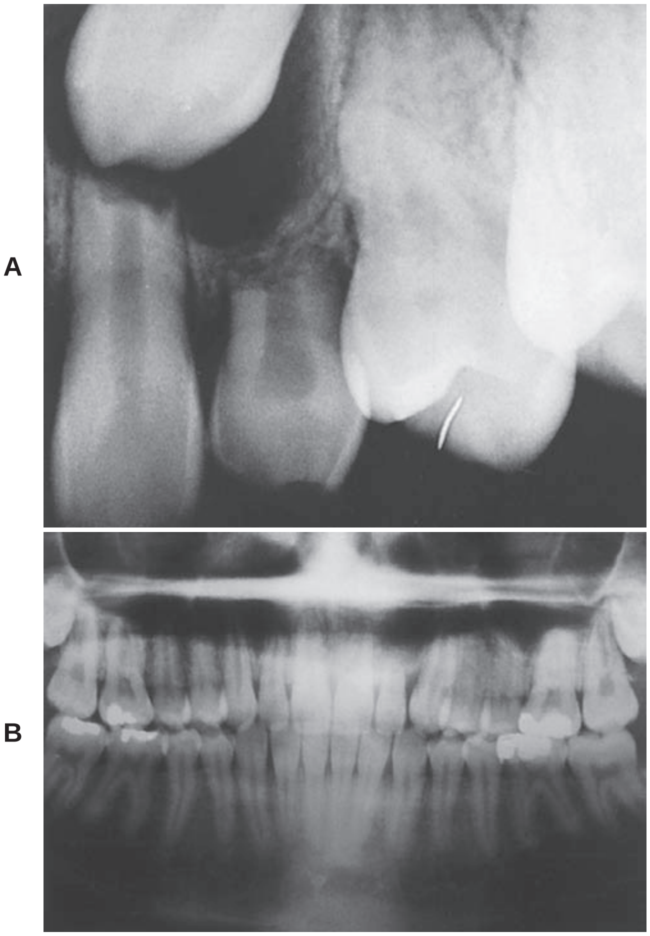

FIGURE 23-24 **A,** Periapical radiograph shows more than 50% resorption of the root of a lateral incisor. The crown of the canine had to be uncovered surgically and kept in contact with the oral cavity. **B,** Panoramic radiograph shows no further resorption of the lateral root in the finished case.

lodges between the roots of a bifurcated first premolar, it is difficult to uncover without getting into the apices of the premolar. This is true whether the canine is uncovered from the palatal or labial side of the arch. In this situation the premolar would have to be extracted to salvage the maxillary canine (Figure 23-25, *E, F*). Labial impactions are much less difficult to manage if a soft tissue grafting procedure is used (Figure 23-26).

Maxillary Palatal Impactions. With maxillary palatally positioned canines, which occur 3 times more often than labially malposed canines, the problem is different. Because the palate is all masticatory mucosa, a graft is not placed on the teeth. To uncover these teeth, the orthodontist reflects the palatal tissue, places a window, and replaces the tissue over the palate (Figure 23-27). A periodontal dressing is kept in place for 7 to 10 days, and then the orthodontist places a bonded attachment and begins tooth movement.

A major orthodontic principle that applies to palatal canines is the importance of using a sufficiently large base arch (at least an 0.018-inch or a rectangular stainless steel base arch). The base arch must be large enough to prevent deflection of teeth in the maxillary arch into the opposing occlusion each time the patient closes the mouth. Devitalization of lateral incisors often occurs when a flexible, multistranded base arch or a light nitinol base arch is used; when the palatally impacted tooth is activated over a long period, it deflects teeth (particularly maxillary lateral incisors) into the opposing occlusion. Lateral incisors also can be devitalized by occlusal trauma. In adults the primary teeth are left in place until the palatally displaced tooth has been moved close to the arch; the primary tooth then is taken out. After removing the primary tooth, the orthodontist places an acrylic pontic on the arch wire for aesthetics.

The orthodontist must evaluate palatally impacted teeth constantly for bleeding around the crown and active bleeding around the tooth; ideally, this is done with a curette. If excess bleeding is noted, the orthodontist should refer the patient back to the general dental office or to the periodontal office for periodic scaling and curettage to remove bacteria from the subgingival area. Bacterial buildup occurs because of the depth of the palatal tissue around unerupted teeth. Otherwise, a small chance exists of loss of attachment on a palatally impacted tooth. At each visit the orthodontist should check any tooth that has been uncovered surgically for excessive mobility. In many instances the dental follicle can grow aggressively around the erupting tooth that has been uncovered and can displace or detach the graft from the crown on labial impactions. The follicle also can cause bone loss around the entire tooth as the tooth is moved into the arch.

If excessive mobility is observed, the orthodontist must refer the patient to the periodontist to find out whether bone is following the erupting tooth. An x-ray examination should be done to determine whether osteoid tissue is present and to ensure that the periodontal attachment is following the tooth as it is guided into the arch. To aid eruption of a deeply positioned palatal impaction, a 0.012- or 0.014-inch stainless steel wire should be twisted until taut directly across the palate from the canine or premolar area to the premolar area on the opposite side of the arch. The authors do not recommend the use of auxiliary springs because these springs tend to overextrude the canine. The orthodontist uses an explorer to tighten the wire with a Spanish windlass technique and then places the attachment on the palatally positioned tooth and ties a power thread from a tooth to the wire that goes across the palate. The force is directed so as to erupt the tooth into the palate out of the palatal soft tissues (Figure 23-28). The orthodontist then rotates the tooth and moves it directly into the arch. If palatal tissue recovers the tooth and the tooth erupts through the palatal tissue into the arch, treatment time is prolonged by many months. Therefore, the tooth should be erupted within 7 to 10 days after the surgical

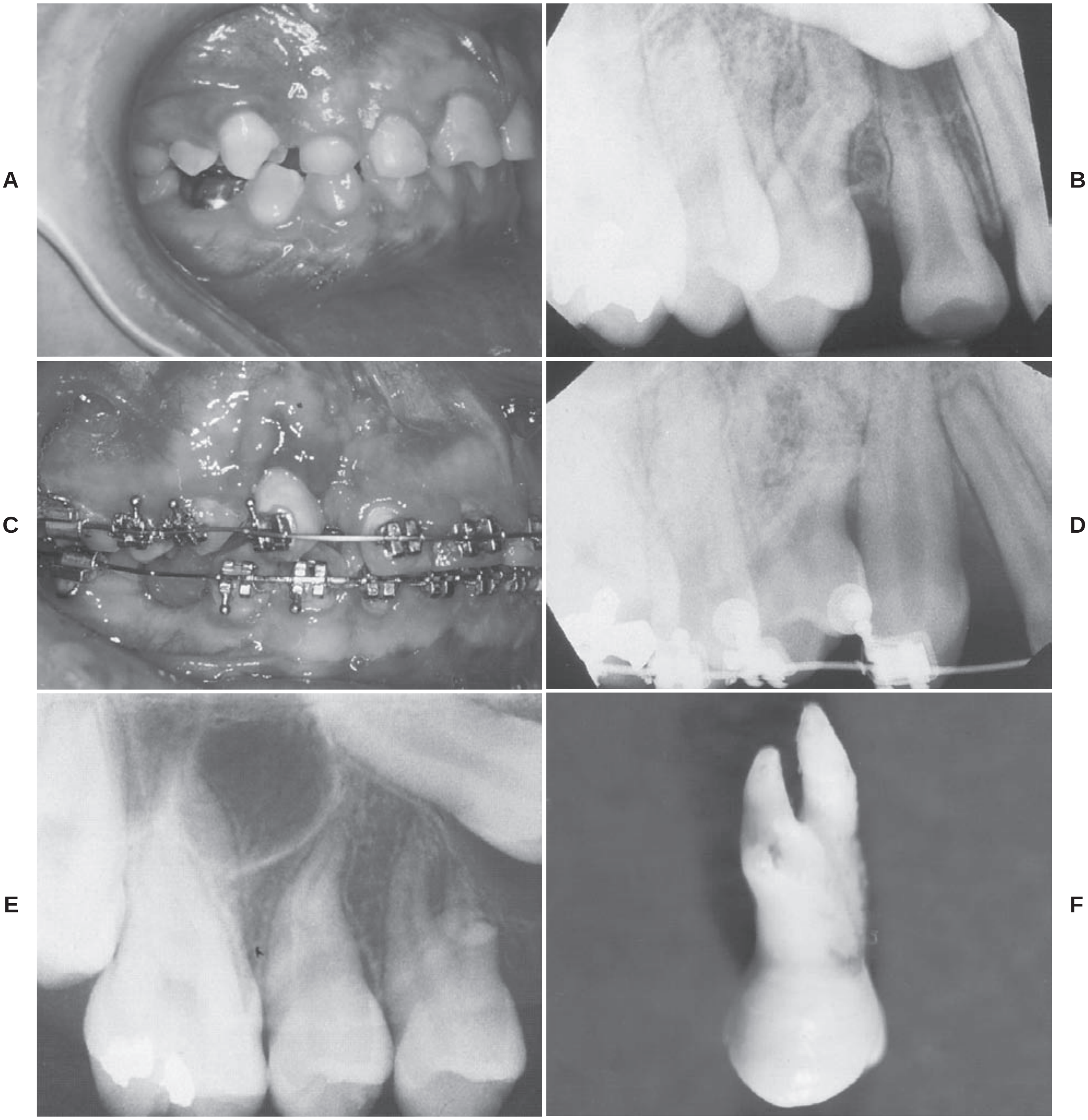

FIGURE 23-25 **A,** Right clinical view of a primary canine still in position before appliances were placed. **B,** On this preoperative periapical radiograph, note the bifurcated first premolar root with the maxillary right canine lodged between the roots. **C,** Several years later, the tooth has been guided anteriorly from the labial into the arch. This is an adolescent boy whose oral hygiene, despite constant reinforcement, remained inadequate; note the significant gingival hyperplasia. **D,** Progress periapical film indicates possible loss of attachment, although the probing depth is minimal**. E,** A young girl with an unerupted maxillary right canine. A pretreatment periapical radiograph shows a bifurcated first premolar. This root form can complicate and prolong treatment. **F,** The premolar was extracted.

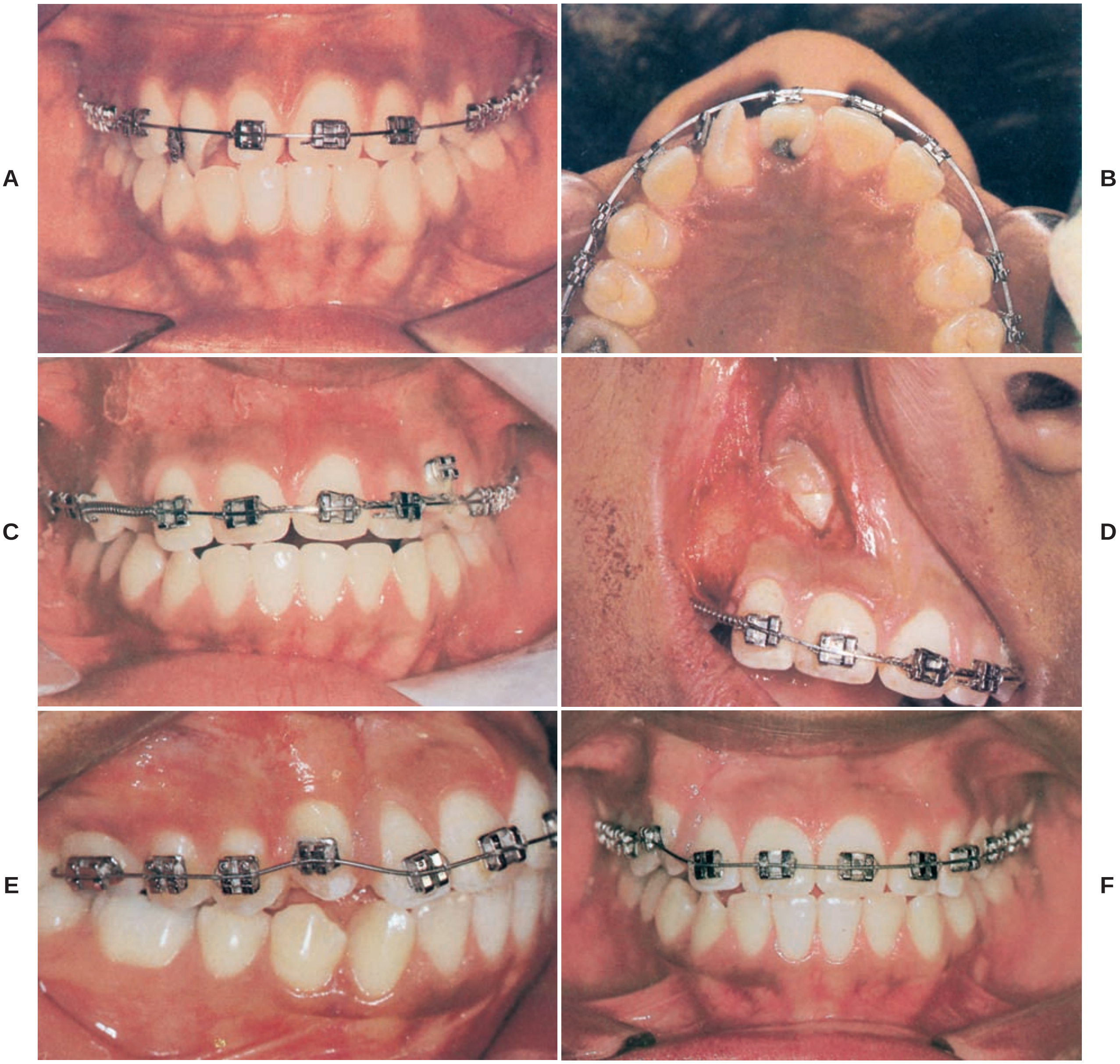

FIGURE 23-26 **A,** A young woman with a supernumerary incisor between the two central incisors. **B,** Palatal view of the supernumerary incisor to the right of the midline. **C,** The supernumerary tooth was removed, and the right central and lateral incisors were positioned properly. **D,** The maxillary right canine was uncovered surgically, and a pedicle graft was placed on the labial. **E,** Note the tissue health as the tooth is moved into position. **F,** Anterior view of the maxillary right canine.

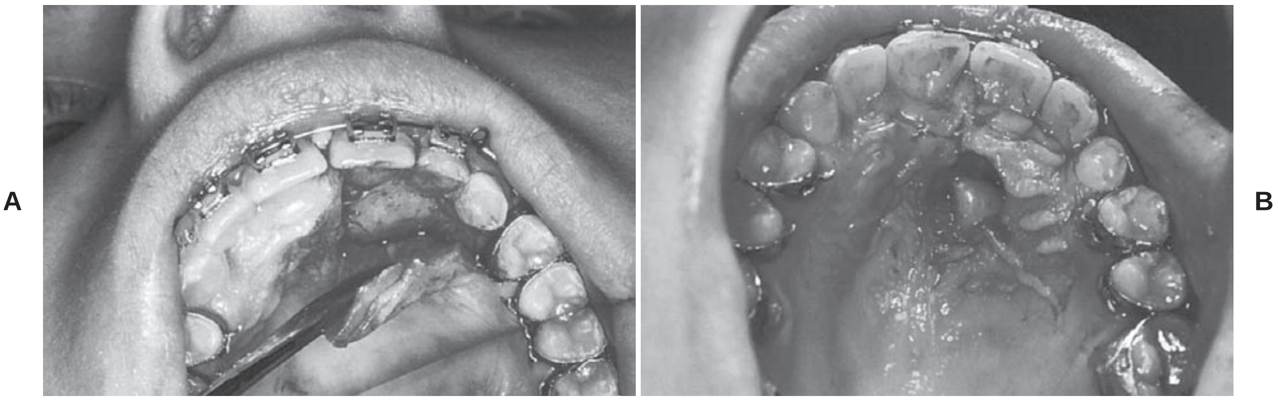

FIGURE 23-27 **A,** An ectopically positioned palatal canine rarely can be palpated. The palatal soft tissue must be reflected, and osseous surgery is required to enter the follicular space. Inadequate exposure not only prolongs treatment but also may result in injury to the tooth because of the inadequate field of vision. **B,** The palatal tissue is put back in position, and a soft tissue window is created in the orientation of the long axis of the anatomic crown.

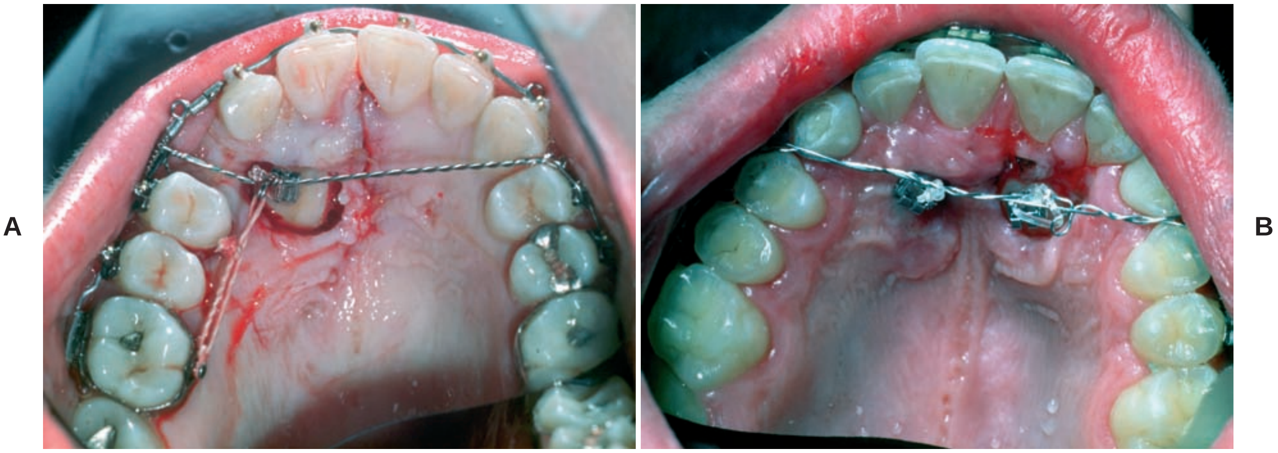

FIGURE 23-28 **A,** A 0.014-inch dead soft stainless steel wire is placed across the palate, with thread used to erupt the canine distally toward the tongue. **B,** A 0.012-inch stainless steel wire is used to tie elastomeric thread to each canine to erupt both teeth to the level of the palatal vault. They then can be guided toward the arch.

procedure and should be erupted down out of the thick tissue and brought to the level of the palatal contour. At this point the orthodontist can determine whether the tooth is backward and needs to be rotated; rotational movement should be initiated immediately (even in the center of the palate) as the tooth is moved toward its proper position in the arch.

Second Premolar and Second Molar Impactions. After the canines, the second premolar is the tooth that most often requires surgical uncovering. As with mandibular premolars, apically repositioned grafts are necessary. If the tooth is located on the lingual, the graft is placed on the lingual only. If the tooth is in the center of the arch (an occlusal radiograph is needed to locate these teeth before they are uncovered), an apically positioned graft on the facial and on the lingual is required (Figure 23-29). Ideally, the orthodontist should give the surgeon as much assistance as possible in determining the location of teeth, as well as any special information about the surgical uncovering. With the mandibular molars, one also must do a buccal and a lingual graft when these teeth are located in the middle of the ridge. The osseous surgery must allow the graft to be placed onto the enamel on the buccal and lingual aspects of the anatomic crown.

Incisor Impactions. Less often, a mandibular incisor (or several mandibular incisors) may need to be uncovered. With mandibular incisors, a labial and a lingual graft must be done, and these grafts must be extended beyond the line angle of each crown (Figure 23-30). If the grafts are not placed beyond the line angle of the unerupted tooth, a mucogingival defect may be created on the line angle, whether it is on the lingual or the facial aspect, even when teeth are in the center of the ridge.

As persons get older, the teeth tend to become ankylosed, particularly as an individual reaches the 30s and

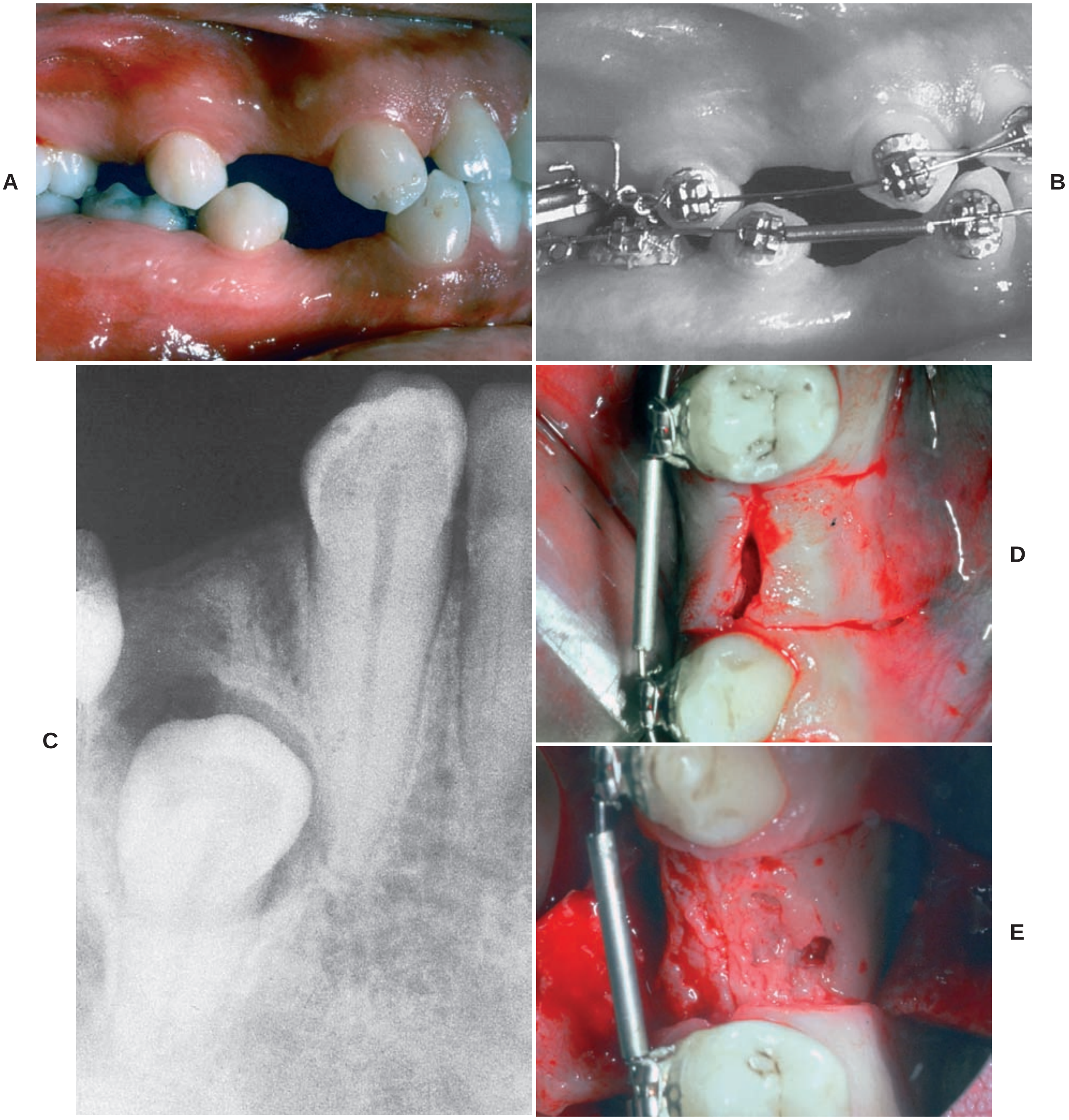

FIGURE 23-29 **A,** A 37-year-old woman who needs alignment in the maxillary right posterior segment before restorative dentistry. The lower right first premolar is impacted and ankylosed. The patient was advised to have the tooth extracted, but she elected to have orthodontic treatment. **B,** Appliances were placed to align the maxillary arch and allow immediate activation of orthodontic force on the lower premolar after it had been luxated. **C,** Preoperative radiograph of the ankylosed first premolar before it was uncovered. **D,** Initial releasing incisions made to mobilize a pedicle graft for the lingual and the facial of the unerupted premolar. **E,** With the tissue reflected, one can see that the premolar is covered completely by bone.

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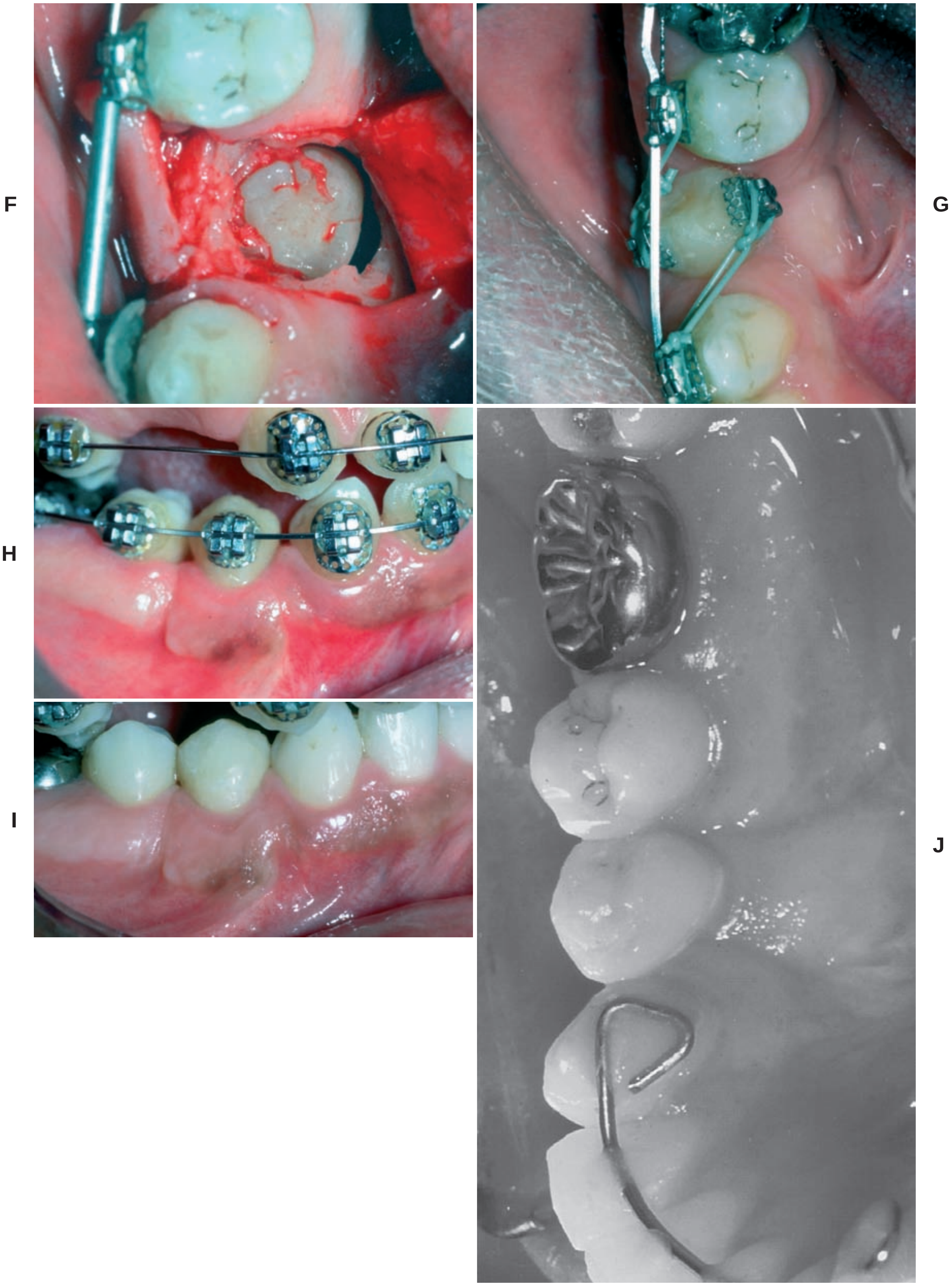


FIGURE 23-29, cont'd **F,** Osseous surgery is performed to uncover the tooth, which is located toward the lingual. The tooth is luxated carefully (moved occlusogingivally) until the area of fusion has been broken. A bonded attachment is placed (bonding should be done only on an ankylosed tooth at the time of surgery), and power thread must be activated within 24 hours and reactivated every 10 days, or the tooth will reankylose. **G,** Two points of attachment are needed to rotate the premolar effectively. **H,** Note that as the tooth moves toward the occlusal plane, the facial gingiva moves with it. **I,** One year after the tooth was positioned in the arch, it had not reankylosed. **J,** On the lingual aspect, note that more gingiva was created as the tooth was erupted. When the tissue attaches to the bone and the tooth (as eruption occurs), more gingiva is created. *(From Hösl E, Zachrisson BU, Baldauf A, editors:* Orthodontics and periodontics*, Chicago, 1985, Quintessence.)*

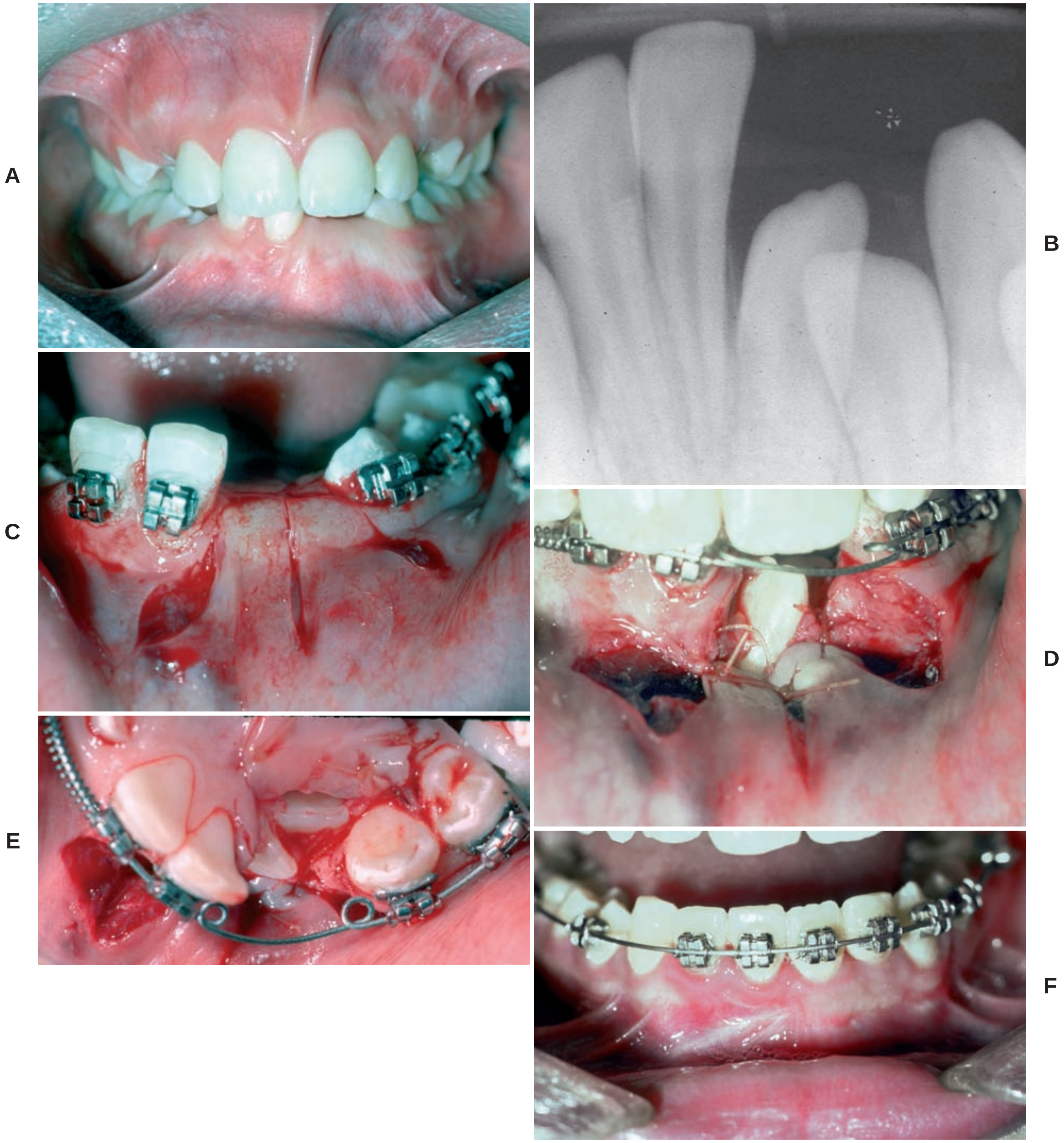


FIGURE 23-30 **A,** An 11-year-old girl in whom the mandibular left central and lateral incisors would not erupt. **B,** Preoperative radiograph of the unerupted mandibular incisors. **C,** Initial incisions made to establish individual pedicle grafts for each incisor on the labial and lingual aspects of the two teeth. **D,** The mandibular arch was bonded and arch wire was placed before the surgical procedure. Individual apically positioned pedicle grafts were placed on the labial surface of each incisor. **E,** Occlusal view showing the apically positioned pedicle grafts that were placed on the lingual aspect of each mandibular incisor. The margins of the grafts were placed on the enamel coronal to the cementoenamel junction area. **F,** Note that the incisors with grafts attached to the enamel on the left central and lateral incisors show normal gingival contour. *(From Schatz JP, Joho J, editors:* Minor surgery and orthodontics*, Chicago, 1992, Quintessence.)*

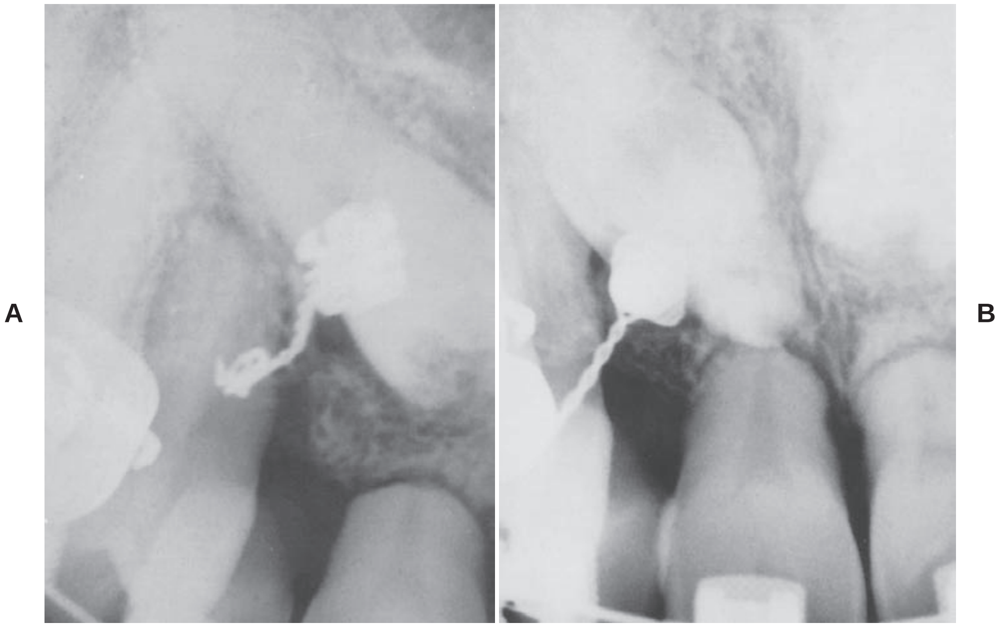


FIGURE 23-31 **A,** Periapical radiograph of a 50-year-old woman; the root is not well defined, and a periodontal ligament space is not evident on the unerupted canine teeth. The pulp also appears to be obliterated. **B,** Both canine crowns seem to fade or blend into the bone. Note the resorption areas on the anatomic crowns of both canines and the bonded incisors. The canines are anklyosed and cannot be moved into the arch.

40s; radiographs can reveal this complication. A radiograph of a tooth that appears to fade into the bone indicates ankylosis (Figure 23-31). Teeth with this radiographic appearance should be considered hopeless, and no attempt should be made to bring them into the oral cavity. All unerupted teeth cannot be salvaged, and the prognosis may be poor. Certain impacted teeth, even the canines, should be extracted. However, the number of successfully treated unerupted teeth can be increased by proper management of the tissues attached to these teeth. Protecting the marginal integrity of the attachment apparatus and preventing an apical shift of the dentogingival junction result in fewer aesthetic deformities and a more favorable long-term prognosis; these goals can be accomplished most effectively by using a pedicle graft, as has been described.

Ankylosis and External Root Resorption. In addition to surgical procedures and orthodontic management of unerupted teeth, impacted teeth present other, more perplexing problems.[68] Most clinicians have been confronted with ankylosis of deciduous and permanent molars in the primary and transitional dentition. Some permanent teeth that have been exposed to the oral cavity are ankylosed. The most common cause of ankylosis generally is believed to be trauma to a tooth. External root resorption commonly is associated with tooth replantation. Many reports have discussed the possible causative factors associated with ankylosis.[69–71]

All too often a clinical orthodontist has ordered extraction of teeth with the expectation of bringing an unerupted tooth into the arch. The oral surgeon exposes the unerupted tooth, and later the orthodontist finds that the tooth will not move. After repeated attempts at luxation, with ankylosis returning, the surgeon removes the tooth. The statement, "one in the mouth is worth two in the gums" may seem to apply.

A high incidence of tooth ankylosis and external root resorption reportedly has been associated with impacted teeth that have been uncovered and ligated with dead soft stainless steel at the cementoenamel junction area[72,73] (Figure 23-32). This procedure,[74] first reported in 1942, still is being used today.[75,76] Use of the wire loop has been called the "simplest and most often used means of attachment … of an unerupted tooth."[77]

However, to tighten a wire placed in the cervical third of an impacted tooth and not impinge on the normal cementoenamel junction–alveolar bone relationship requires an extreme amount of surgical finesse. This form of attachment can cause permanent loss of crestal bone at the time the tooth is ligated. In addition, the wire may damage the tooth and act as an irritant on the tooth side of the periodontal ligament space; this could result in injury or create an environment (in a susceptible patient) prone to ankylosis (Figure 23-32, *C–I*). Recent studies in periodontal wound healing have clarified the biologic response that allows replacement resorption and ankylosis. The wire can damage the cells on the tooth side of the periodontal ligament and prevent apical downgrowth of epithelium, which can protect the root against resorption and ankylosis. Granulation tissue derived from bone now is known to induce resorption and ankylosis. Ankylosis, however, always occurs at the

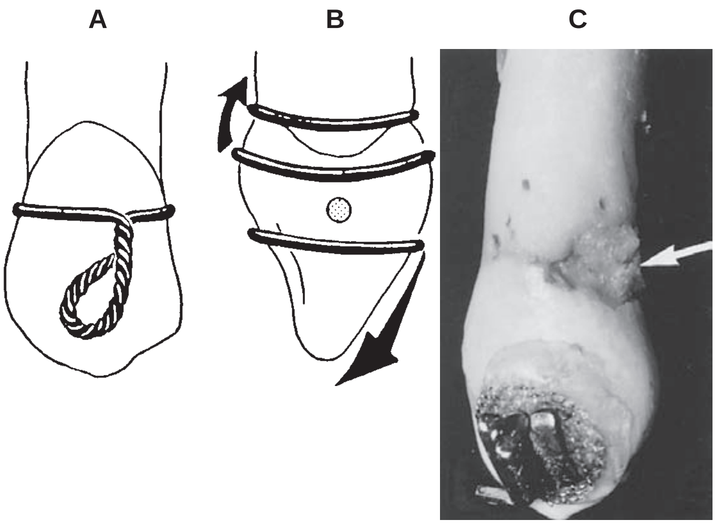
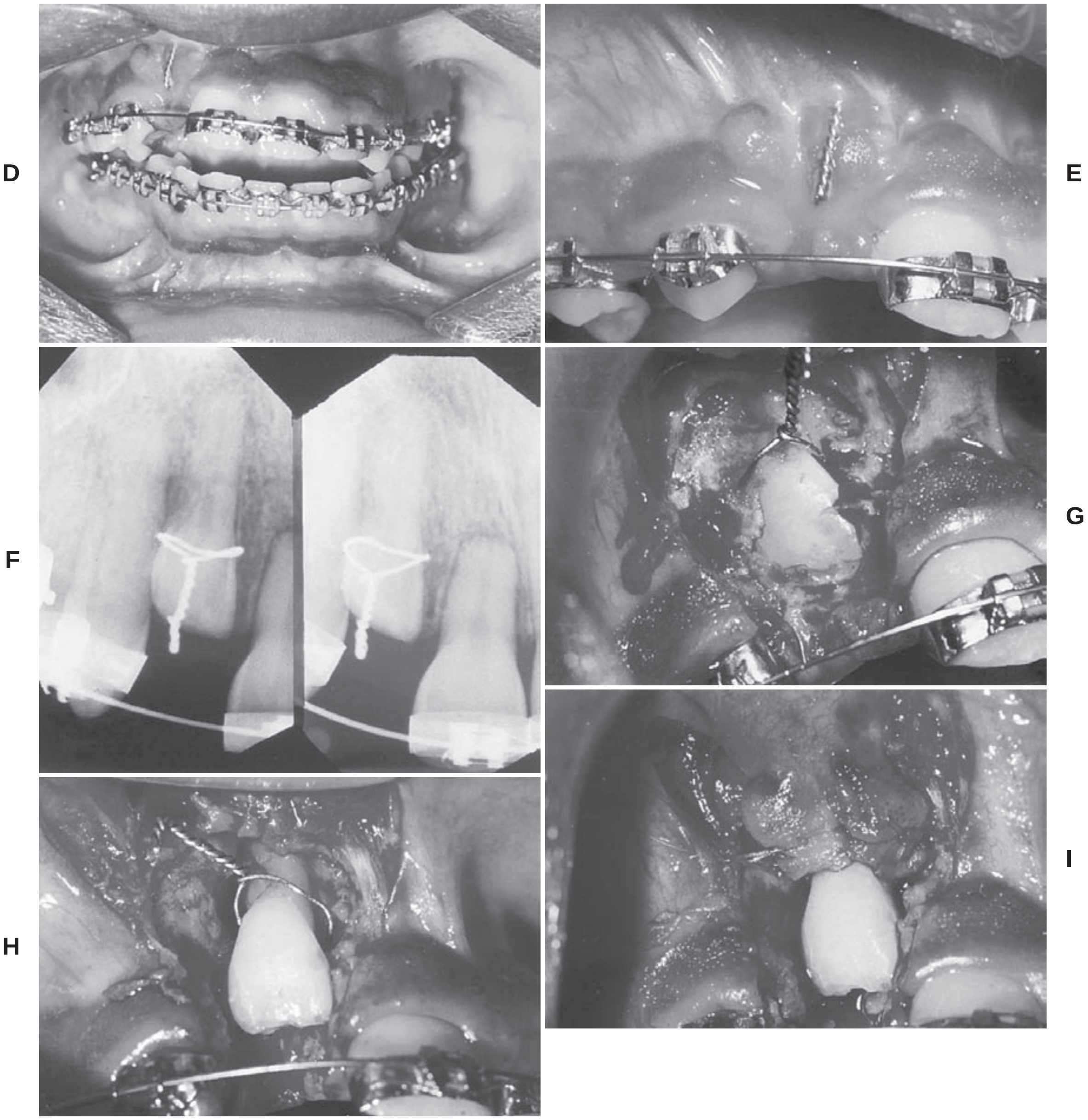


FIGURE 23-32 **A,** Diagrammatically, the ligature tied in the area of the cementoenamel junction (if it were to stay above the contact area) will move incisally and come off the tooth. **B,** If the tooth is ligated below the contact area, the ligature will tend to move apically and impinge on the cementoenamel area, damaging the root surface. **C,** An extracted canine that was uncovered surgically and ligated with a wire loop. The bone invading the root had spread from the cementoenamel junction area into the root and the anatomic crown. **D,** In the case of this 16-year-old girl, the lateral incisor was uncovered and a wire looped attachment was placed by the surgeon; ankylosis occurred. The ankylosed lateral incisor caused an openbite by intruding the maxillary arch as wire changes continued. **E,** Wire that penetrated the alveolar mucosa was tied to the base arch by elastomeric thread. **F,** Note the radiographic appearance of bone invading the root apical to the wire loop. **G,** On reflection of the soft tissue, note the bone over the wire loop and invading the tooth. **H**, Osseous surgery was performed to create a sound tooth structure, and all bone attached to the root was removed. **I,** A pedicle graft was placed on the tooth, which was salvaged.



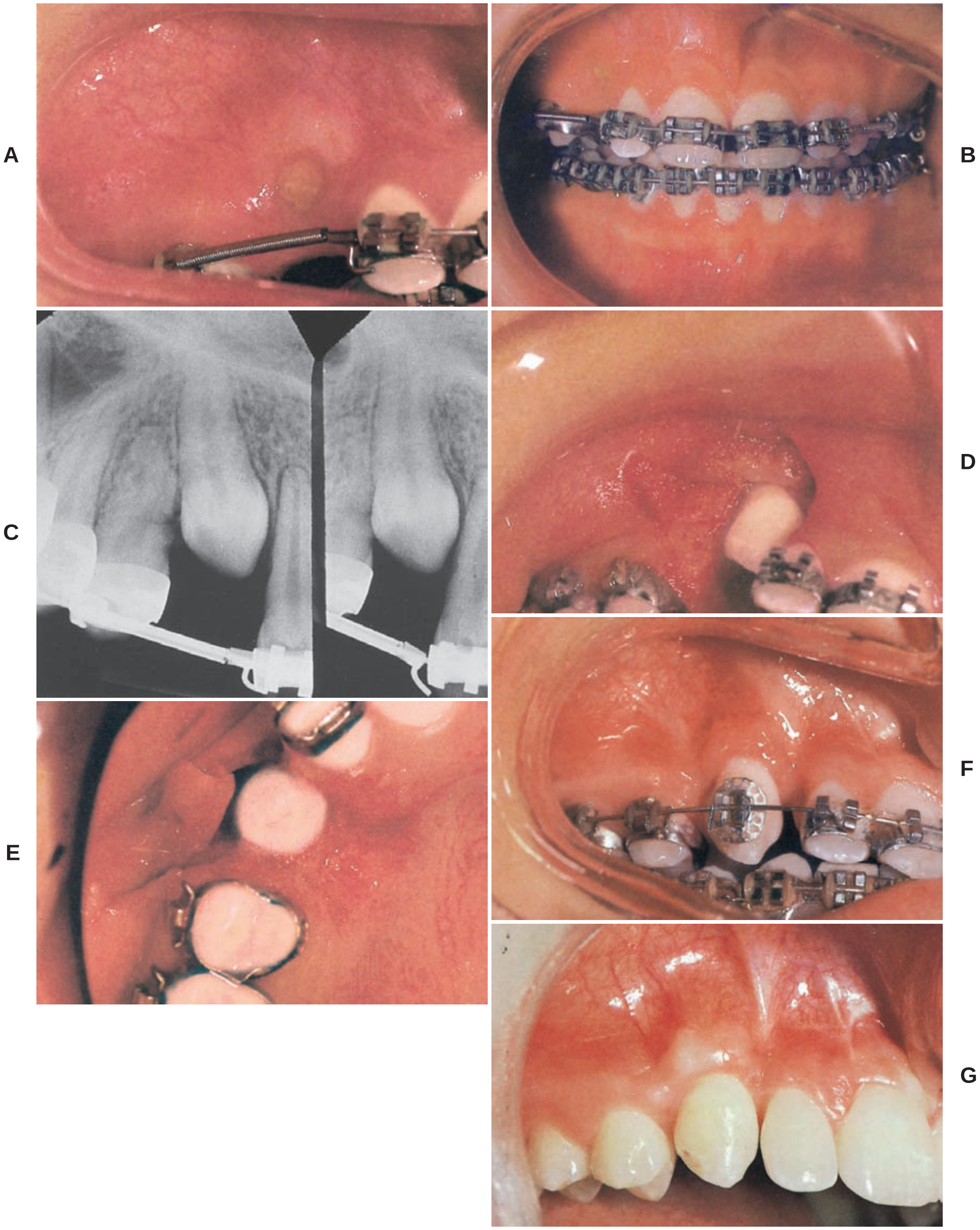


FIGURE 23-33 **A,** Note the labial aspect of a partly exposed maxillary right canine that had been uncovered on three previous occasions. **B,** Anterior view after the arch had been intruded and leveled again. **C,** Periapical radiograph made when the tooth was uncovered. **D,** An apically positioned graft was placed on the labial. **E,** A small area of spot ankylosis was found and removed on the palatal aspect, and the tooth was moved into the arch. **F,** The tooth has been in the arch for 2 months after the surgical procedure. **G,** Appliances were removed, and the tooth was stable.

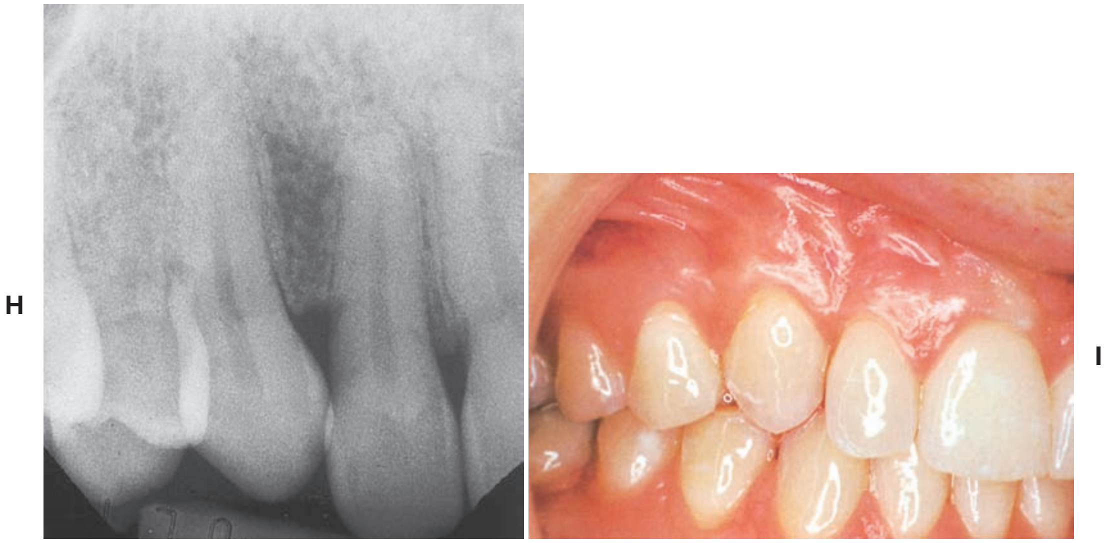


FIGURE 23-33, cont'd **H,** Periapical radiograph made 18 years later. **I**, Eighteen-year follow-up finds excellent function of the tooth.

crestal area where the wire is positioned. One hypothesis is that the circumferential destruction of the periodontal ligament extending from the cementum to the bone may be a necessary prerequisite for ankylosis.[5] Several researchers have suggested that ankylosis can occur because of the repopulation of the periodontal ligament from the adjacent bone marrow.[78,79]

The mechanism of injury and ankylosis is becoming better understood[80]; however, patients with this problem predictably show one common denominator: all demonstrate rapid healing clinically. In periodontics, supracrestal external root resorption has been reported to occur when fresh hip marrow with cancellous bone was used as osseous autograft material. The wire loop also may allow inflammation to be established in the area of resorption. The replacement resorption may be arrested by removal of the bone, or the tooth may become extensively resorbed at the crestal area.

Usually, when teeth that show external root resorption are exposed (if one assumes that ankylosis has been allowed to exist for a short period), only a small area (1 to 2 mm) is involved. The bone can be removed with a chisel, and the tooth can be orthodontically positioned into the arch, with continuous force being placed 1 day after the tooth is uncovered surgically and is freed up (Figure 23-33). If the force is allowed to dissipate for any length of time, the tooth may become reankylosed. After the tooth has been freed from the bone by osseous surgery or luxation (so that the tooth has a vertical component to the mobility), the force must be reactivated every 10 days.

Many teeth that are ankylosed do not have crestal external root resorption or crestal ankylosis that can be seen on tissue reflection, thus allowing the ankylosed spot to be removed surgically. These teeth can be freed merely by luxation, and an immediate continuous force can be used to position the tooth orthodontically into the arch. Multirooted molars or canines with dilacerated roots have a poorer prognosis for movement after luxation than normally shaped, single-rooted teeth. Because of crestal replacement or resorption (or ankylosis), tooth extraction may be prevented by osseous surgery to remove the bone attached to the tooth, followed by orthodontic movement into the arch, and reestablishment of the normal anatomic crown for the tooth using restorative dentistry.

One should understand that all ectopically positioned or ankylosed teeth cannot be treated successfully. However, a higher percentage of success can be achieved with unerupted teeth by attending to normal development, supporting tissue, atraumatic surgery, bonded attachments, control of gingival inflammation, and use of minimal orthodontic forces.

SUMMARY

No attempt has been made in this chapter to provide a complete discussion of orthodontic and periodontal interrelationships. The intent has been to highlight frequent problem areas. Gingival retention procedures, management of adult patients, and correction of periodontal problems are discussed in Chapter 23. Research information and documented periodontal problems—gathered from clinical observation, clinical trials, animal research, and retrospective analysis—are sufficient to allow the formulation of clinical guidelines for achievement of orthodontic objectives in problem cases; the ultimate objective is that the patient will be better off for having received treatment. Periodontal problems have not been eliminated for all patients, but significant progress has been made toward prevention of many adverse responses.

About 10% of adolescents, as well as patients with special problems and adult patients, remain a periodontal challenge for the future. For the orthodontist, the prerequisite for providing effective treatment is a periodontal knowledge base sufficient to prevent periodontal injury.

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CHAPTER 24

Adult Interdisciplinary Therapy:

Diagnosis and Treatment

Robert L. Vanarsdall, Jr., David R. Musich

OUTLINE

- **Current Status of Adult Interdisciplinary Therapy**
- **Goals of Adult Interdisciplinary Therapy**
  - Ideal Orthodontic Treatment Goals and the Adult Patient
  - Individualized Adult Interdisciplinary Orthodontic Treatment Objectives
  - Additional Adult Treatment Objectives
- **Diagnosis of Adult Orthodontic Conditions**
  - Skeletal Differential Diagnosis
  - Periodontal Differential Diagnosis
  - Temporomandibular Joint Differential Diagnosis
- **Clinical Management of the Interdisciplinary Adult Therapy Patient**
  - Biomechanical Considerations
    - *Control of Occlusion*
  - Periodontal Management during the Orthodontic Tooth Movement
    - *Significance of Tooth Mobility*
    - *Periodontal Preparation of Adults before Orthodontic Therapy*
  - Behavioral Management
    - Orthodontist and Staff Preparation for Adult Interdisciplinary Patient Management
- **Sequence of Adult Interdisciplinary Therapy**
  - Skeletal Evaluation
  - Periodontal Preparation
- **Dentoalveolar Collapse: Orthodontic and Restorative Considerations in the Adult Interdisciplinary Patient**
  - Application of Principles
  - Conclusion for AIT Patients with Missing Teeth and Dentoalveolar Collapse
  - Evaluation before Debonding or Debanding
  - Coordination of Debonding or Debanding with Other Treatment Providers
- **Stability and Retention Individualized for the Interdisciplinary Adult Therapy Patient**
  - Communicating with Team Members
- **Risk Management and the Adult Interdisciplinary Therapy Patient**
- **Summary**

CURRENT STATUS OF ADULT INTERDISCIPLINARY TREATMENT

In the past several years, however, a major reorientation of orthodontic thinking has occurred regarding adult patients. The following list cites several reasons for the increased interest by orthodontists in adults as patients, as well as several reasons for increased interest shown by adults in orthodontic treatment:

In 1971 Lindegaard et al.[1] stated that three main factors determine which problems (including adult interdisciplinary conditions) could be treated from both a medical and an orthodontic point of view:

1. A disease or an abnormality must be present.
2. The need for treatment should be determined by the clinical gravity of the disorder, the available resources for orthodontic care, the prognosis for successful treatment, and the priority for orthodontic care based on personal and professional judgment.
3. The patient must have a strong desire for treatment.

In this context, the past 30 years have seen a major change in orthodontic practices. Changed lifestyles and patient awareness have increased the demand for adult orthodontic treatment, and multidisciplinary (more appropriately called interdisciplinary) dental therapy has allowed better management of the more complicated and unique requirements of the adult patient population, thereby greatly improving quality of care and treatment prognosis.[2]

Department chairs of several teaching institutions participating in a round table discussion concerning

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the future of orthodontics[3] made significant statements regarding adult orthodontic therapy. At a conference in 1976, Reidel and Dougherty most accurately predicted the status of adult orthodontic treatment today. Reidel was supportive regarding the future of adult therapy, adding that the clinician should not forget adjunctive orthodontic services provided by periodontists and restorative dentists. Dougherty claimed that "orthodontics is total discipline and it makes no difference whether the patient is young or old."[3]

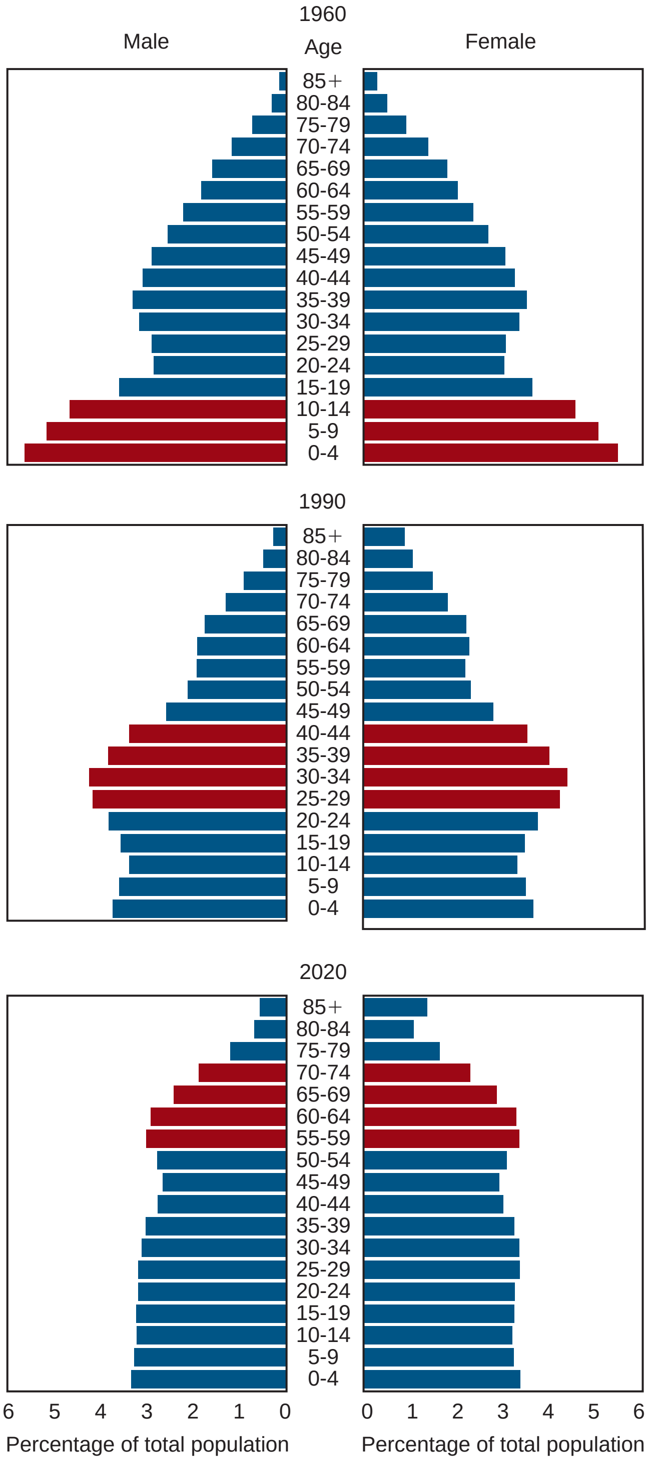
Demographics of the American population further dictate that orthodontists provide services sought by "aging baby boomers."

The Population Reference Bureau, a nonprofit demographic study group in Washington, DC, has predicted that by 2025, Americans over 65 will outnumber teenagers by more than 2:1. According to the U.S. Census Bureau, by 2030 the median age is expected to be 41. By 2050, it is likely that as many as one in four Americans will be older than 65. Many demographers consider these projections to be very conservative; by some estimates, the median age will eventually reach 50 (Figure 24-1). Thus, the demographic considerations demonstrated here and illustrated in Figure 24-2 emphasize the importance of orthodontists developing the skills necessary to manage the increasing number of interdisciplinary adult orthodontic patients.

In addition to recent improvements in treatment techniques and changes in treatment philosophies, important statistical reasons explain why orthodontists have become more involved in the management of the adult patient (see Figure 24-1).[4] Practices that grew reported a higher percentage of adult patients than those that did not grow. The treatment of adults was rated significantly higher as a practice-building method by growing practices than by declining practices. As the volume (percentage) of adult patients increased in orthodontic practices, the skills required of the orthodontist changed. Musich's 1986 paper demonstrated the scope of treatment planning considerations[5] (Figure 24-3). Of the almost 1400 consecutively examined adults in Musich's study, about 70% to 75% of the sample required multidisciplinary management to attain optimal treatment outcomes.

When treating adults, the orthodontist needs to be prepared to do the following:

1. Determine which cases require orthognathic surgical management and which ones require incisor reangulation to camouflage the skeletal base discrepancy
2. Diagnose different stages of periodontal disease and the associated risk factors
3. Diagnose temporomandibular joint (TMJ) dysfunction (TMD) before, during, or after tooth movement
4. Work cooperatively with a team of other specialists to give the patient the best outcome. It is to be noted that



Source: U.S. Bureau of the Census

FIGURE 24-1 Percent of U.S. population by age and sex: 1960, 1990, and projections for 2020. Note the graphic illustration of the aging of the U.S. population. The implications for providing optimal interdisciplinary dental therapy to provide the best quality of life for our aging population are quite clear.

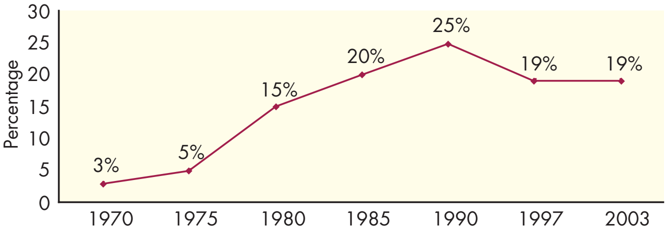


FIGURE 24-2 This graph illustrates an 800% increase of adult patients in the United States receiving orthodontic treatment from 1970 to 2003. The median percentage of patients identified as adults in orthodontic practices seems to have leveled off or even decreased as a percentage of the total number of patients in braces. The actual number of adults in orthodontic therapy probably has increased and has the potential to increase even more as more sophisticated and aesthetic methods of providing care are used. (From Keim RG, Gottlieb EL, Nelson AH, et al: 2003 JCO orthodontic practice study. 1. Trends, J Clin Orthod 37:545–553, 2003.)

the orthodontist must frequently take a *leadership role* in both the diagnosis and the treatment planning of the adult interdisciplinary therapy (AIT) patient.

GOALS OF ADULT INTERDISCIPLINARY THERAPY

Ideal Orthodontic Treatment Goals and the Adult Patient

In 1972, Andrews described the Six Keys to Normal Occlusion, and this description of orthodontic treatment objectives is still the standard by which orthodontic treatment results are measured. More recently, the American Board of Orthodontics sought to quantify further optimal treatment (November 1998, AJODO).[6]

However, adult patients have many preexisting conditions that are not seen in the adolescent population, including tooth loss, severe skeletal dysplasias, periodontal disease, and various forms of TMD. Frequently, the preexisting conditions that are present in the adult patient interfere with the achievement of orthodontists' general idealized goals. In such adult cases, an attempt to achieve ideal tooth positions that are feasible only in dentitions with a Class I skeletal relationship may be considered overtreatment. This is not to say that the orthodontic therapy provided is any less precise; rather, it suggests a need to customize orthodontic treatment for the individual patient so that the achievement of any one goal (perhaps facial aesthetics) does not undermine a less obvious but equally important functional need.

Problem-oriented synthesis of the dental needs of each case will help determine specific treatment objectives that must be established before the orthodontic treatment plan can be determined. Beginning treatment without knowing the specific goals for the individual patient or with unrealistic goals can lead to treatment failure.

In addition to goal clarification, adult patients desire treatment efficiency, convenience in appointment times, and good communication with other health care providers. Both the examination and consultation should allow for two-way communication so the orthodontist and the patient understand the treatment process. Unlike the typical adolescent, an adult may exhibit rapid (within 2 to 3 months) periodontal breakdown and bone loss. Therefore, adult therapy requires the establishment of goals and efficient mechanotherapy so that completion ("get in and get out") occurs as expeditiously as possible.

Individualized Adult Interdisciplinary Orthodontic Treatment Objectives

The generally applied orthodontic treatment goals of (1) dentofacial aesthetics, (2) stomatognathic function, (3) stability, and (4) static and dynamic Class I occlusion often may not be realistic or necessary for all adult patients. Treatment in which general goals are not achieved is not necessarily compromised; rather the mechanotherapy should satisfy the objective of providing the minimal dental manipulation appropriate for the individual case. Many Class I occlusal goals can be considered overtreatment for patients who also require restorative dentistry, prosthetics, plastic surgery, and other multidisciplinary dentofacial corrections. Box 24-1 contains a list of additional goals particularly useful for adult problems requiring toot replacement but not requiring surgical skeletal correction.

Additional Adult Treatment Objectives

1. **Parallelism of abutment teeth.** The abutment teeth must be placed parallel with the other teeth to permit insertion of multiple unit replacements and allow for restorations that involve both the anterior and posterior teeth. A restoration will have a better

BOX 24-1 Additional Orthodontic Treatment Goals in Adult Treatment

Parallelism of abutment teeth
Most favorable distribution of teeth
Redistribution of occlusal and incisal forces
Adequate embrasure space and proper tooth position
Acceptable occlusal plane and potential for incisal guidance at satisfactory vertical dimension
Adequate occlusal landmark relationships
Better lip competency and support
Improved crown/root ratio
Improvement or self-correction of mucogingival and osseous defects
Improved self-maintenance of periodontal health
Aesthetic and functional improvement
Best outcome with least risk (using minimally invasive approach)

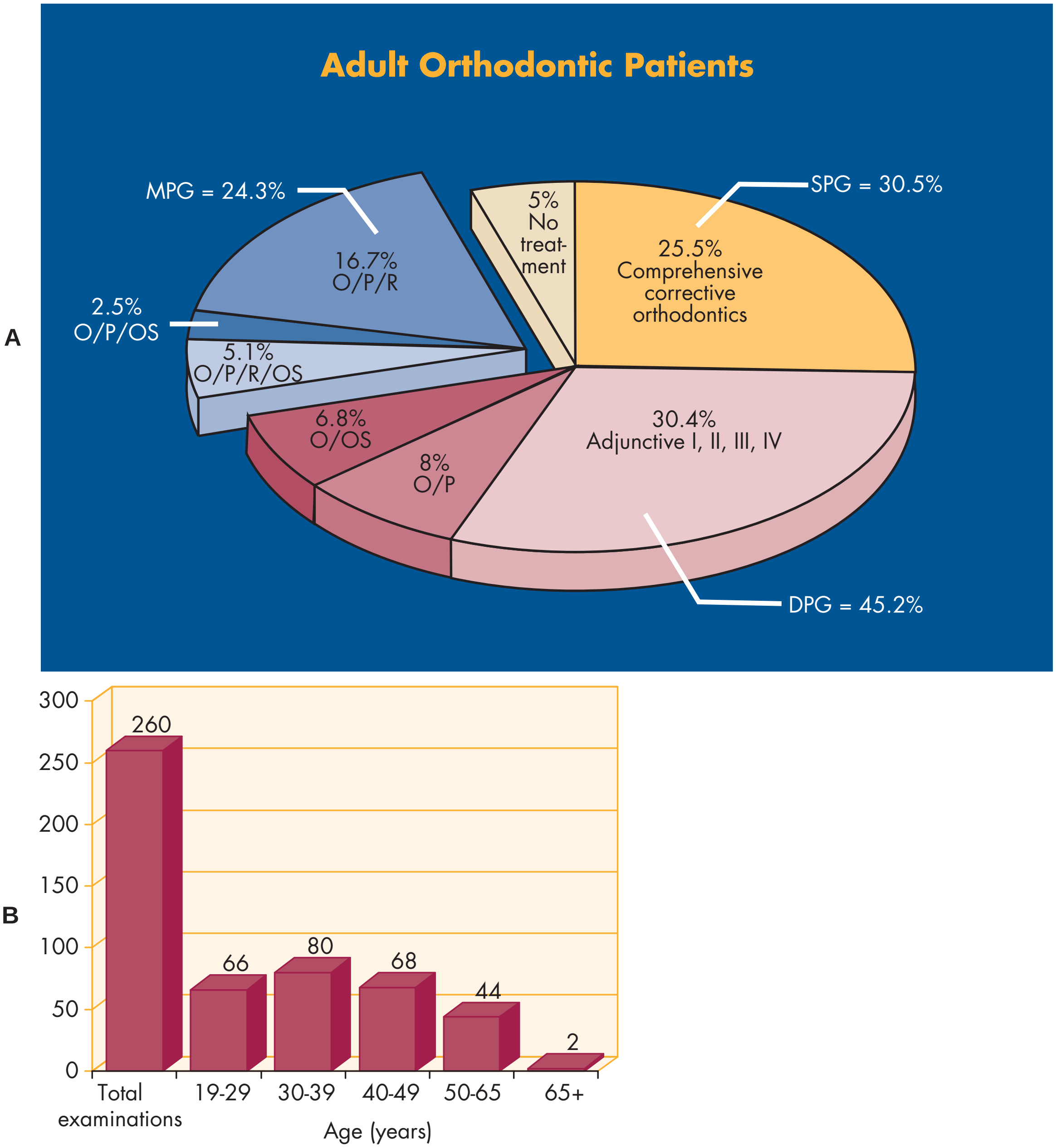


FIGURE 24-3 **A,** A summary diagram of findings from Musich's study[5] of 1370 consecutively examined adults: 30.5%, solo provider group (SPG)—25.5% required conventional corrective orthodontics; 45.2%, dual provider group (DPG)—within this group two primary providers were required to complete the treatment (orthodontist/restorative dentist [O/R], 30.4%; orthodontist/periodontist [O/P], 8.0%; orthodontist/oral surgeon [O/OS], 6.8%); and 24.3%, multiple provider group (MPG). Note that 5% required no orthodontic treatment and 65% required dual or multiple provider therapy. **B,** Graph showing number of adults examined by author according to age. Note that 90% of adults were examined between the ages of 19 and 49 years of age.

Adult Patients Redefined: 19 to 80 Years

Age (yr)	Abbreviated Social Factors
19–29	Many still in transition to adult level of independence
30–39	Pressure, pregnancy (70% of adults seeking orthodontic care are women), stress, money, temporomandibular joint
40–49	Time for self (before it is too late)
50–65	Use of insurance, prepare for retirement, other health issues ("stay younger longer")
66–80	Preserve and restore, major role of interdisciplinary therapy including implants

Graph based on a recommended division of adult patients by decade of life, which may factor into treatment decisions.

prognosis if the abutment teeth are parallel before tooth preparation,[7] because that position does not require excess cutting or devitalization during abutment preparation and allows for a better periodontal response. For full-arch splints, the posterior teeth should be reasonable parallel to anterior abutments. Parallel abutments allow for better restorative retention and help prevent cement washout and caries (Figure 24-4).

2. **Most favorable distribution of teeth.** The teeth should be distributed evenly for replacement of fixed and removable prostheses in the individual arches (Figure 24-5). In addition, they should be positioned so that occlusion of natural teeth can be established bilaterally between arches.[8]
3. **Redistribution of occlusal and incisal forces.** Cases with significant bone loss (60% to 70%) require that occlusal forces be directed vertically along or on the long axis of the roots to maintain the occlusal vertical dimension (Figure 24-6). When the posterior teeth are missing, the anterior teeth can be positioned to allow for more axially directed transfer of force and can then be reshaped to function as posterior teeth (supporting the vertical dimension).[8]
4. **Adequate embrasure space and proper root position.** This allows for better periodontal health, especially when the placement of restorations is necessary (Figure 24-7). The anatomic relation of the roots is important in the pathogenesis of periodontal disease,[9] interproximal cleaning, and placement of restorative materials.[10]
5. **Acceptable occlusal plane and potential for incisal guidance at satisfactory vertical relationship**. To establish the acceptable occlusal plane for a mutilated dentition exhibiting bite collapse, the Hawley bite place (Figure 24-8) is inserted with the platform

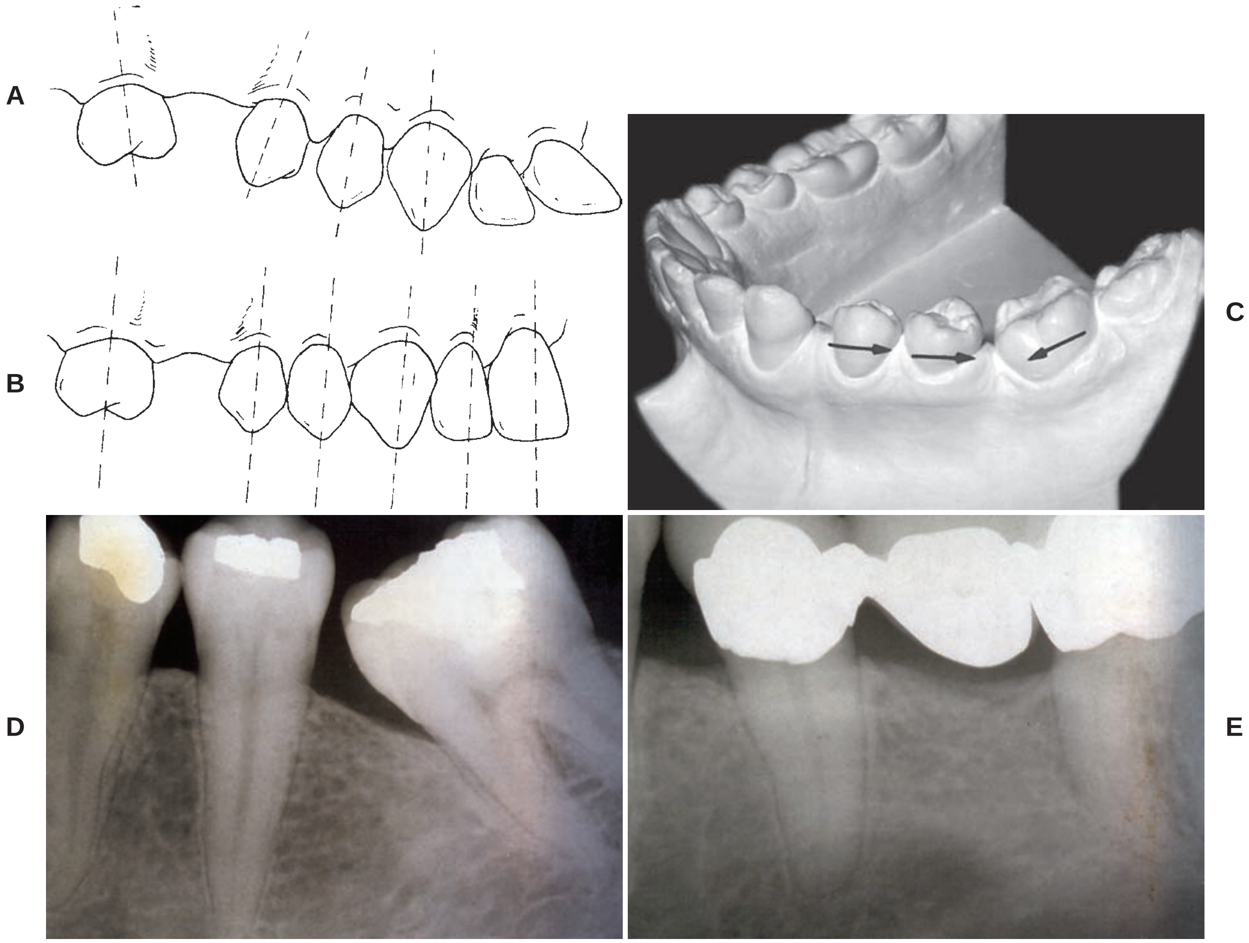


FIGURE 24-4 Clinical example of adult treatment objective 1: parallelism of abutment teeth. **A,** Drifting and flaring of the maxillary teeth caused by mutilation, periodontal disease, and occlusal and muscular forces. **B,** Orthodontic preparation. This should produce parallelism of the anterior and posterior segments before restorative dentistry that involves full arch stabilization. **C,** Lower model of collapsed arch with missing No. 19. **D,** Radiograph of tilted molar. **E,** Molar uprighted and restoration placed with roots parallel. Orthodontic reangulation of teeth adjacent to missing teeth is an important goal to facilitate long-term periodontal health and the aesthetics of the replacement tooth in posterior and anterior portions of the mouth.

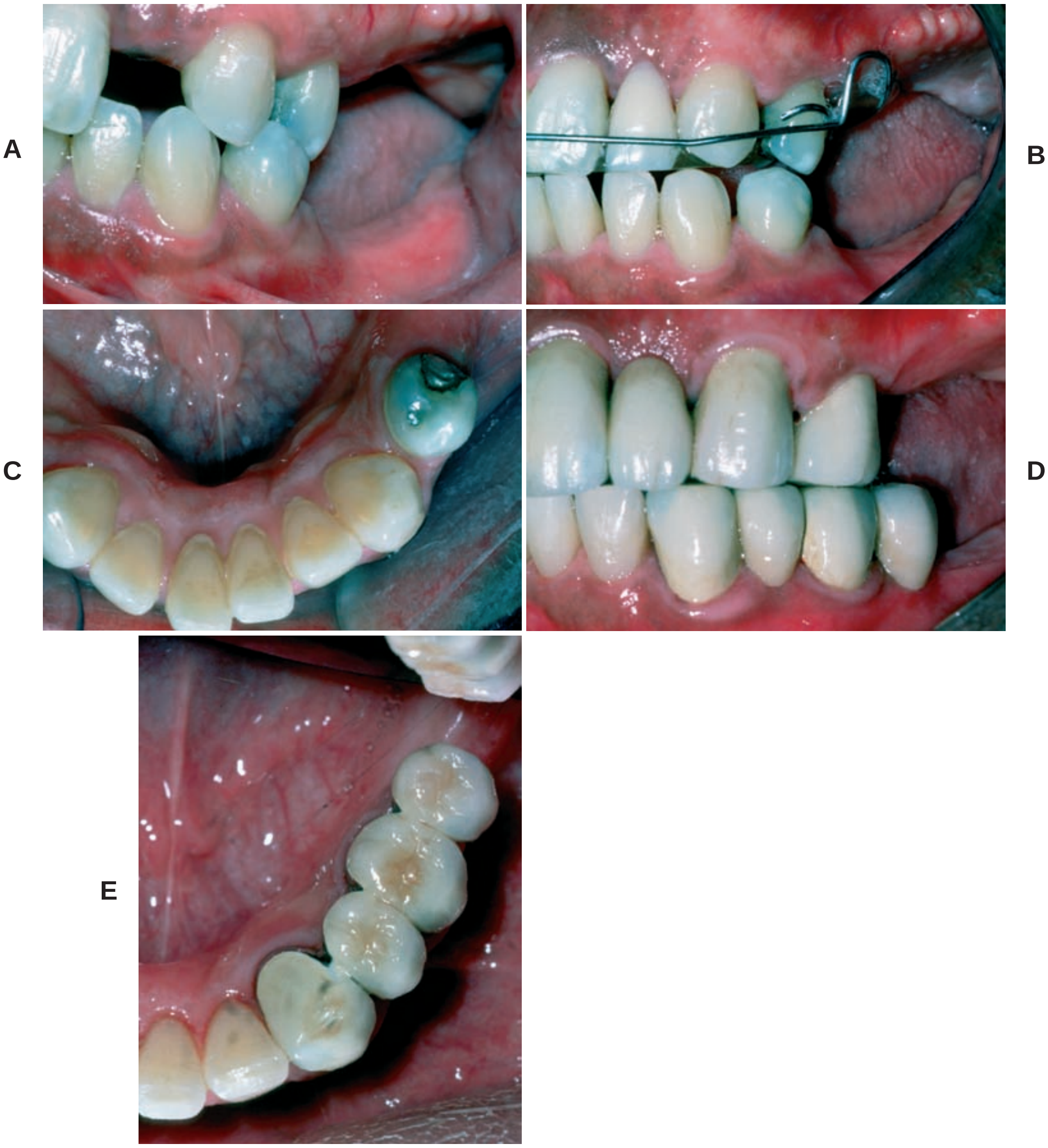


FIGURE 24-5 Clinical example of adult treatment objective 2: most favorable distribution of teeth. **A,** First premolars, the only teeth present in the left maxillary and mandibular quadrants of a 56-year-old man. **B,** A combination of fixed and removable appliances was used to move the mandibular first premolar one pontic space distally in the left quadrant. **C,** Preoperative. Note the lower left first premolar adjacent to the canine. **D,** Final restoration. Distal movement of the first premolar abutment created a pontic space between the canine and the distal premolar abutment. **E,** Better distribution of abutments allowed for this lower left four-unit restoration, preventing the need for a distal extension partial denture or implants.

of the anterior plane adjusted at a right angle to the long axis of the lower incisors.[11] This allows a centric relation at an acceptable vertical relationship.

Even with extended platforms in Class II patterns, patients can usually speak well. However, if the vertical dimension is excessive, they will whistle involuntarily and complain of muscle fatigue in the morning, or the acrylic will develop etched lines or wear streaks. When properly adjusted at the correct vertical height, the bite plane will allow simultaneous bilateral neuromuscular activity. It is important that no contact occurs between the posterior teeth during excursive movements and no interferences occur between anterior teeth while the bite plane is in place. Such interferences will prevent the patient from demonstrating simultaneous bilateral neuromuscular activity and correct location of centric relation.

The curve of Spee should be mild to flat bilaterally. This is difficult to achieve if supraerupted molars are present. However, the most extruded posterior segment will be the ruling factor in determining the potential for an orthodontic solution at an acceptable vertical. Adult molars with amalgam restorations and normal pulpal recession and mixed constrictions often can be occlusally reduced 2 to 4 mm and still allow for placement of restorations

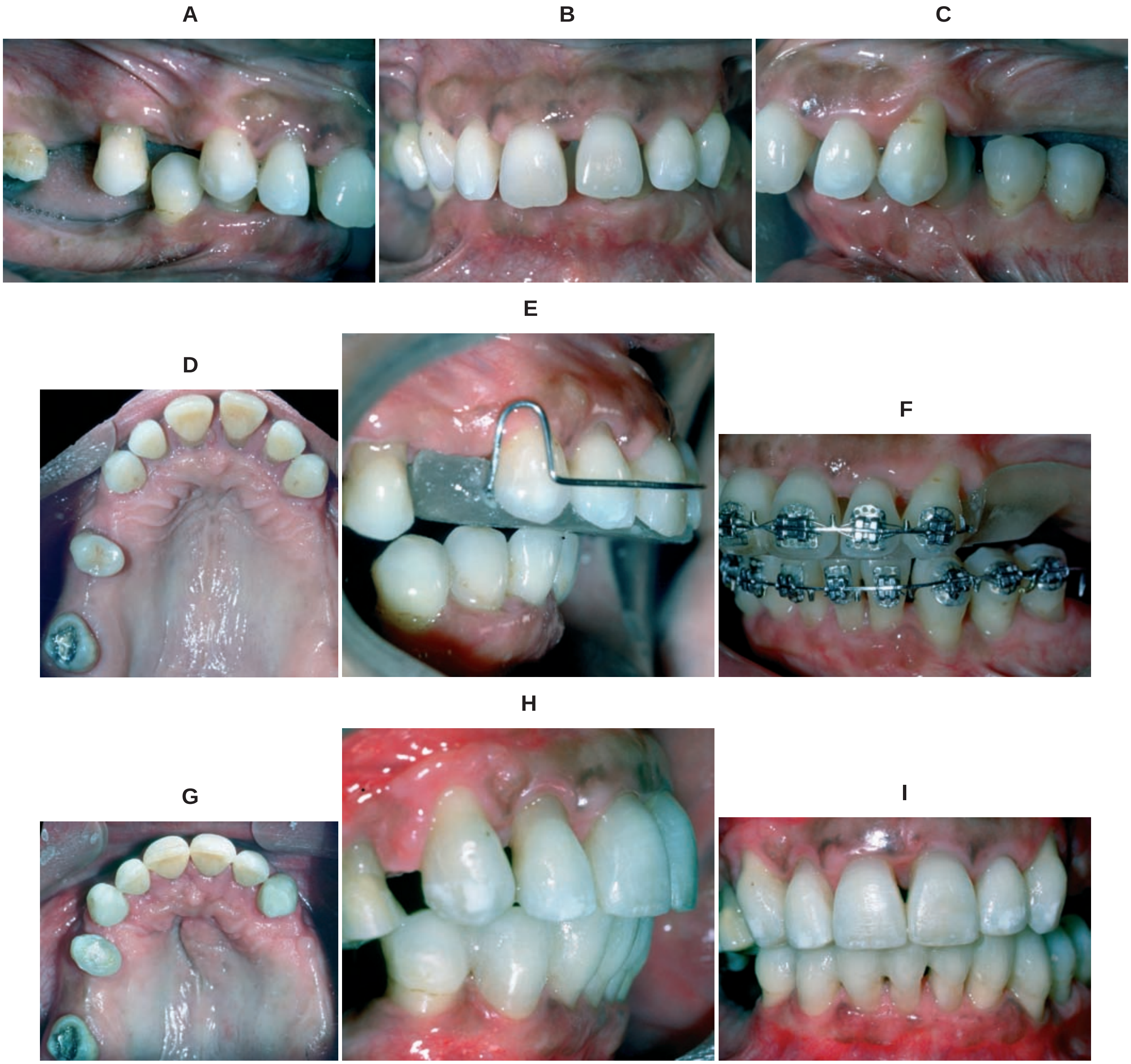


FIGURE 24-6 Clinical example of adult treatment objective 3: redistribution of occlusal and incisal forces. **A,** No natural tooth stops in a 45-year-old woman. The initial tooth contact in centric relation was between the mandibular first premolar and the maxillary second premolar. **B,** Anteriorly, the mandible fits within the maxillary arch. **C,** No tooth contact on the left side. **D,** Soft tissue indentations indicate the location of lower incisor contact with the palate. **E,** Severe maxillary protrusion. A Hawley bite plane was used to locate centric relation at the acceptable vertical. **F,** After maxillary and mandibular alignment, a splint was placed before maxillary segmental osteotomy. The osteotomy positioned the maxillary canines axially to contact the lower dentition bilaterally. **G,** After surgery, occlusal platforms placed on the maxillary canines support the vertical dimension. **H,** Three years posttreatment. **I,** Lower anteriors bonded with composite resin as a form of retention.

Continued

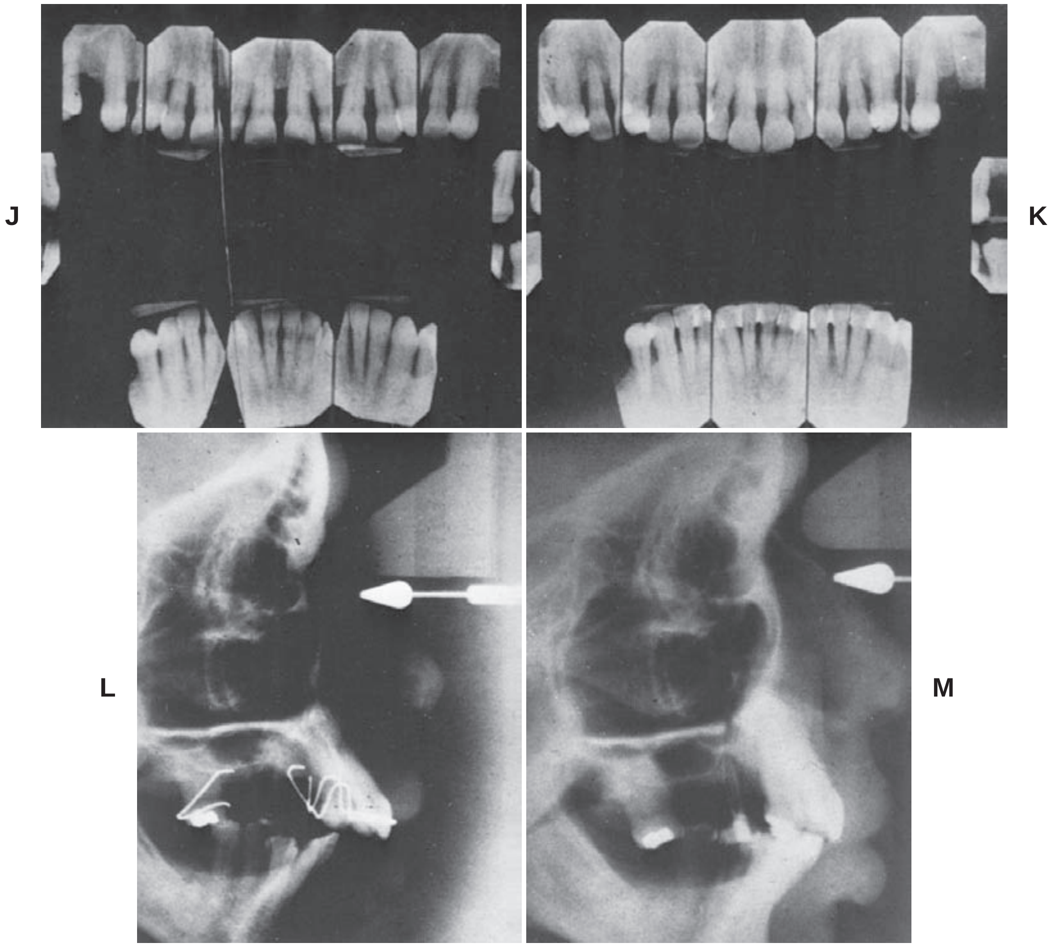


FIGURE 24-6, cont'd **J**, Pretreatment. **K,** Three years posttreatment. **L,** Pretreatment cephalogram. Acceptable vertical dimension. **M,** One year posttreatment.

without the need for revitalization. With the aid of heavy musculature, molars may be intruded 1 to 2 mm in treatment. The unilateral orthodontic treatment of an accentuated occlusal plane should be avoided; one side cannot be left extruded.

6. **Adequate occlusal landmark relationships.** As previously described for adult patients, the transverse dimension is the most difficult to correct and maintain orthodontically, the sagittal next, and the vertical least. However, when teeth are to be restored, they must be positioned to achieve acceptable buccolingual landmarks. Posterior crossbites involving surgery should be positioned so that the maxillary buccal cusps contact the lower central fossae with the crossover for incisal guidance in the premolar area or the canine positions (Figure 24-9).
7. **Better lip competency and support.** Many adults have long upper lips that preclude significant maxillary retraction. In cases requiring anterior restorations, retraction is recommended to achieve lip competency while maintaining lip support. The restoration then can be shaped to provide incisal guidance on the canines or by 1- or 2-mm palatal extension of the incisors. Incisors extended more than 1 or 2 mm palatally cause constant palatal soft tissue irritation. In some Class II, division 1 cases (when orthognathic surgery is rejected) the lower incisors can be advanced into a more procumbent position than the usual orthodontic norm to establish incisal guidance. With the aid of bilateral posterior flared positions (incisor mandibular plane angle [IMPA] 105 to 120 degrees). In some Class III patients as well, the maxillary incisors can be kept in stable relation (even though more flared than normal) with posterior restorations. Inadequate support may create a change of anteroposterior and vertical position of the upper lip and increase wrinkling. This often makes the face seem prematurely aged and is a major aesthetic concern of adults, especially women, who are usually anxious about changes of the upper lip (Figure 24-10).
8. **Improved crown-to-root ratio.** In adult patients who have lost bone on individual teeth, the length of the clinical crown can be reduced with the high-speed handpiece; as the tooth is erupted orthodontically (the same amount of bone will remain on the clinical root), the ratio of crown to root will be improved (Figure 24-11).[94]

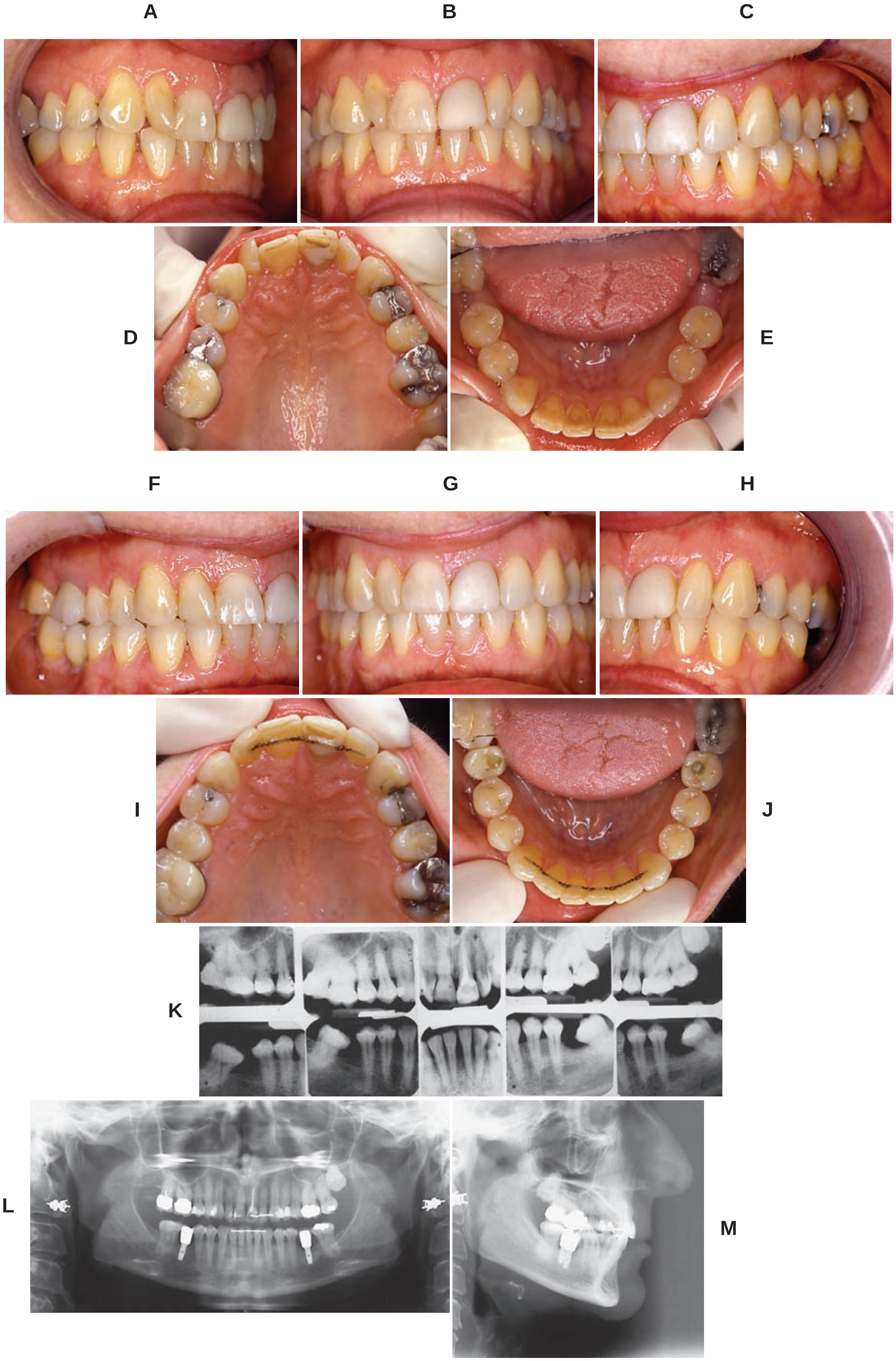


FIGURE 24-7 Clinical example of adult treatment objective 4: adequate embrasure space and proper root position. **A–E,** Pretreatment intraoral photographs showing compromised embrasures and altered root position of lower second molars preventing proper restorations. **F–J,** Posttreatment intraoral photographs showing corrected crown and root position. Note No. 7 rotation correction and lower anterior spacing correction. **K,** Pretreatment radiographs. Note rotated No. 7 and No. 10 and tilted Nos. 18 and 31. **L,** Long-term panoramic radiograph. Note the continued stability of Nos18, 19, 30, and 31 and the previously rotated No. 7 at 7 years after orthodontic treatment. **M,** Long-term cephalogram. Note the continued stability of the posterior occlusion 7 years after orthodontic treatment.

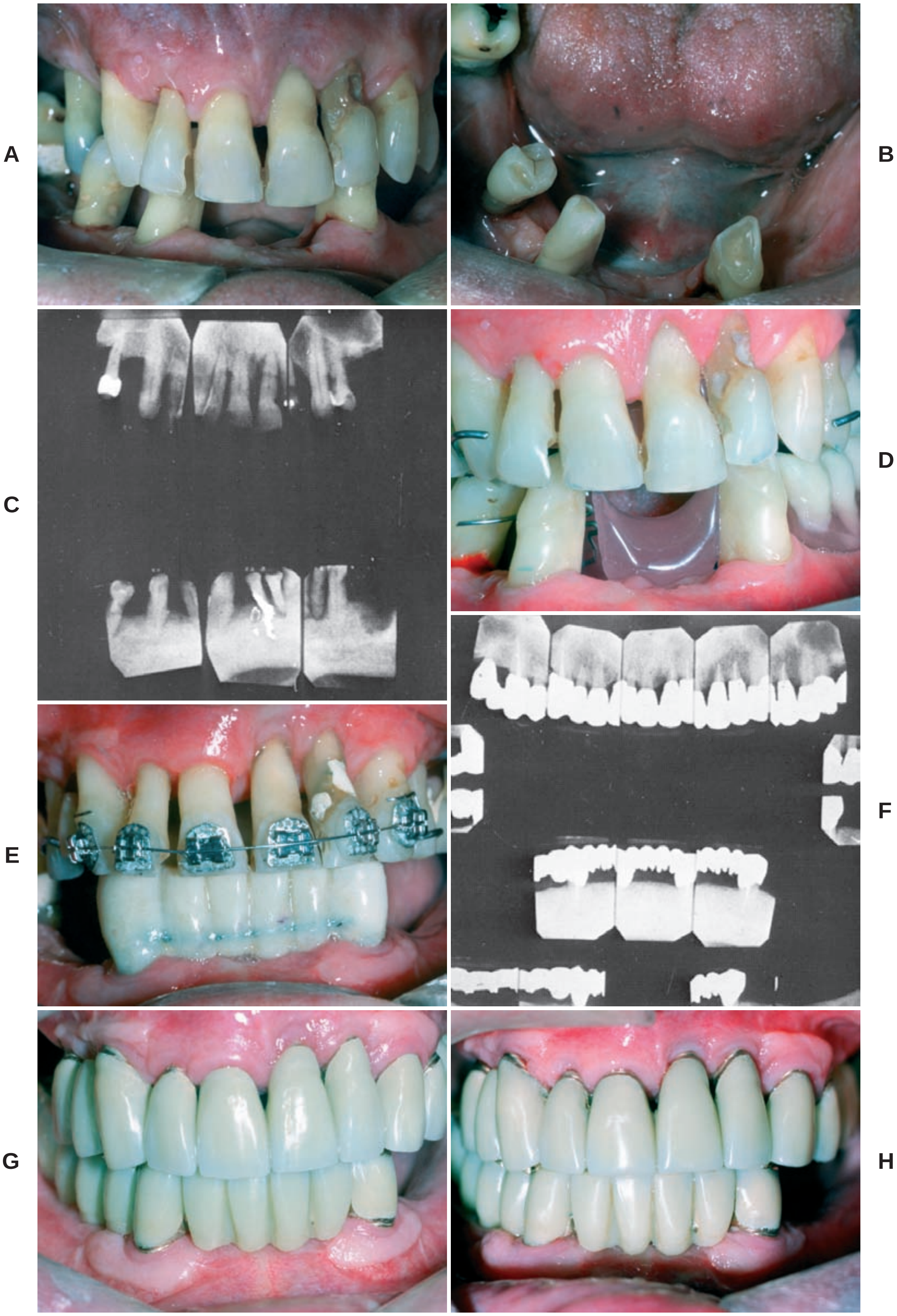


FIGURE 24-8 Clinical example of adult treatment objective 5: acceptable occlusal plane and potential for incisal guidance at satisfactory vertical dimension. **A,** No occlusal stops bilaterally in a 61-year-old patient. The lower right premolar had only soft tissue attachment. **B,** Lower canines tipped lingually and mobile. **C,** Preoperative. **D,** Upper and lower removable appliances were placed to support the vertical height and move each lower canine labially over its basal support. **E,** After the lower canines were positioned axially, the restorative dentist (Dan Casullo, Philadelphia) placed a provisional restoration. A platform then was added to the upper appliance (to determine the satisfactory vertical), and the maxillary incisors were aligned. **F,** Seven years postoperative. **G,** Final restoration. **H,** Twenty-year follow-up of patient with advanced attachment loss.

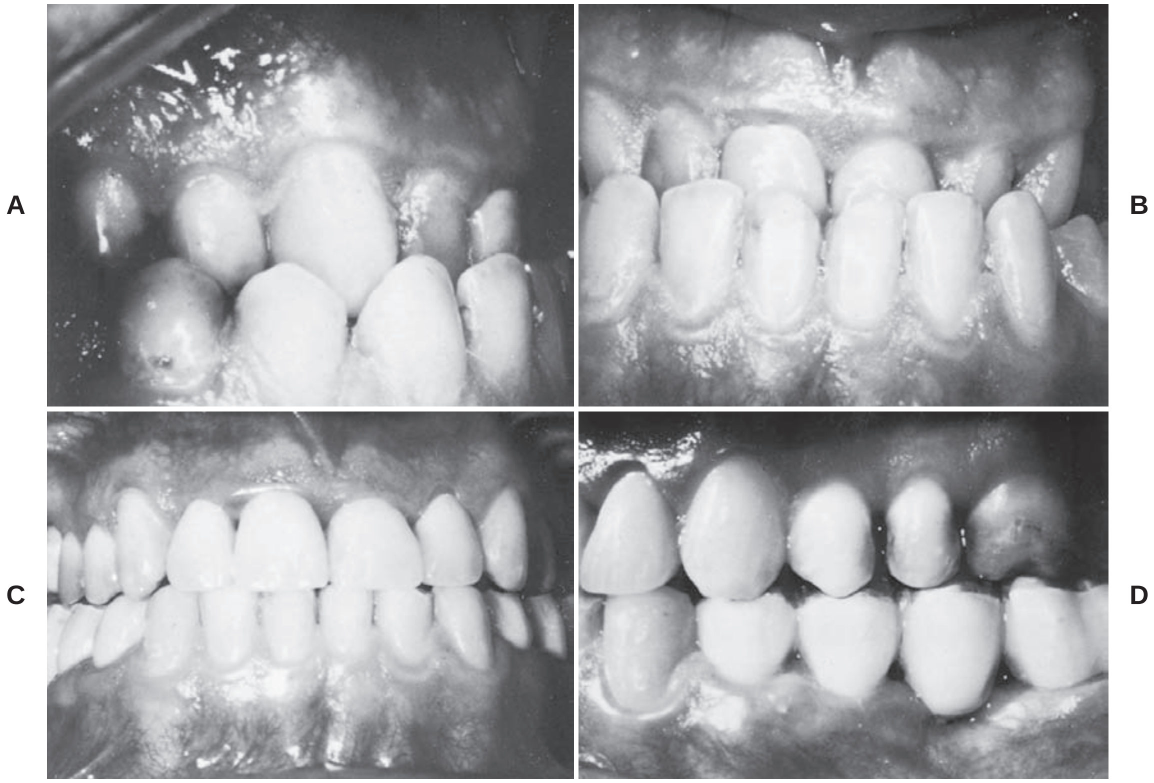


FIGURE 24-9 Clinical example of adult treatment objective 6: adequate occlusal landmark relationships. **A, B,** Class III relationship with severe transverse skeletal discrepancy that required lower posterior reconstruction. **C,** The anterior segment could be positioned normally to provide incisal guidance. The posterior occlusion was left in crossbite because of the maxillary transverse deficiency. **D,** Note the occlusal scheme that allows the crossbite to occur in the premolar area.

9. **Improvement or correction of mucogingival and osseous defects.** Proper repositioning of prominent teeth in the arch will improve gingival topography (Figure 24-12). In adolescents, the brackets are placed to level marginal ridges and cusp tips. In adults, the goal should be to level the crestal bone between adjacent cementoenamel junctions. It has been demonstrated that the need for osseous and mucogingival surgery may be diminished by favorable changes of the osseous and soft tissue topography during tooth movement. Therefore, attachments should be placed on individual teeth to allow the leveling of the attachment apparatus. This creates more physiologic osseous architecture with the potential to correct certain osseous defects.[14a] During leveling stages any teeth that have erupted above the occlusal plane should be grossly reduced occlusally. Also, continuous adjustment should be done to prevent the patient from contacting individual posterior teeth prematurely and causing occlusal trauma.
10. **Better self-maintenance of periodontal health.** The location of the gingival margin is determined by the axial inclination and alignment of the tooth. Clinically, it appears that improved self-maintenance of periodontal health occurs with proper tooth position.[15–17] This can be seen in adult patients as a result of correction of bite collapse and accelerated mesial drift (see Figure 24-12).

    Patients who need weekly periodontal maintenance during initial leveling phases of therapy may require less frequent scaling and root planning as periodontal status improves. Poor tooth position and improper tooth preparation before irreversible restorative dentistry are causative factors that may contribute to periodontal disease. For better periodontal health on an individual pattern basis, teeth should be positioned properly over their basal bone support. In the nonsurgical management of skeletal Class III and Class II malocclusions, a delicate balance exists between periodontally desirable tooth positions and achievement of other nonsurgical treatment objectives.
11. **Aesthetic and functional improvement.** As stated previously, a plan should provide acceptable dentofacial aesthetics and allow for improved muscle function, normal speech, and masticatory improvements. This is possible when a therapeutic occlusion is provided that enables the anterior teeth to function as disarticulators and the posterior teeth to support the vertical dimension (Figure 24-13).[11]
12. **Best outcome with least risk** (**using minimally invasive approach**). As technology increases therapeutic options, it is more incumbent on the

Text continued on p. 858

FIGURE 24-11 Clinical example of adult treatment objective 8: improved crown-to-root ratio. **A,** Before correction of an incisor crossbite. Note the normal gingival position on the labially displaced lower left lateral incisor in a 14-year-old patient. After lower incisor alignment the gingival margins were confluent. **B,** Narrow zone of attached gingiva in a 61-year-old patient. As the lower incisors were retracted and allowed to erupt, more gingiva was created incisogingivally. **C,** Adult female with large osseous defect on the mesial of the lower left premolar. Note the significant probing depth. **D,** Preoperative radiograph of intrabony defect. **E,** Before orthodontic movement, guided tissue regeneration was used to create new attachment, and then eruption was used to eliminate any remaining osseous defect. Note nonresorbable membrane that was placed over the defect, which was allowed to heal, and was removed 8 weeks later. **F,** The tooth was extruded to resolve the intrabony defect. **G,** Buccal view of the preoperative intrabony defect. **H,** Buccal view of the new bone after the tooth was extruded and prepared for a restoration. **I,** Lingual view of the preoperative intrabony defect. **J,** Lingual view of the new bone after regeneration and tooth movement. **K,** Provisional restoration. The osseous defect has been corrected and the crown-to-root ratio has been improved. **L,** Radiographic appearance of the premolar. (C–J, Courtesy Eric Saacks, Bondi Junction, Australia.)

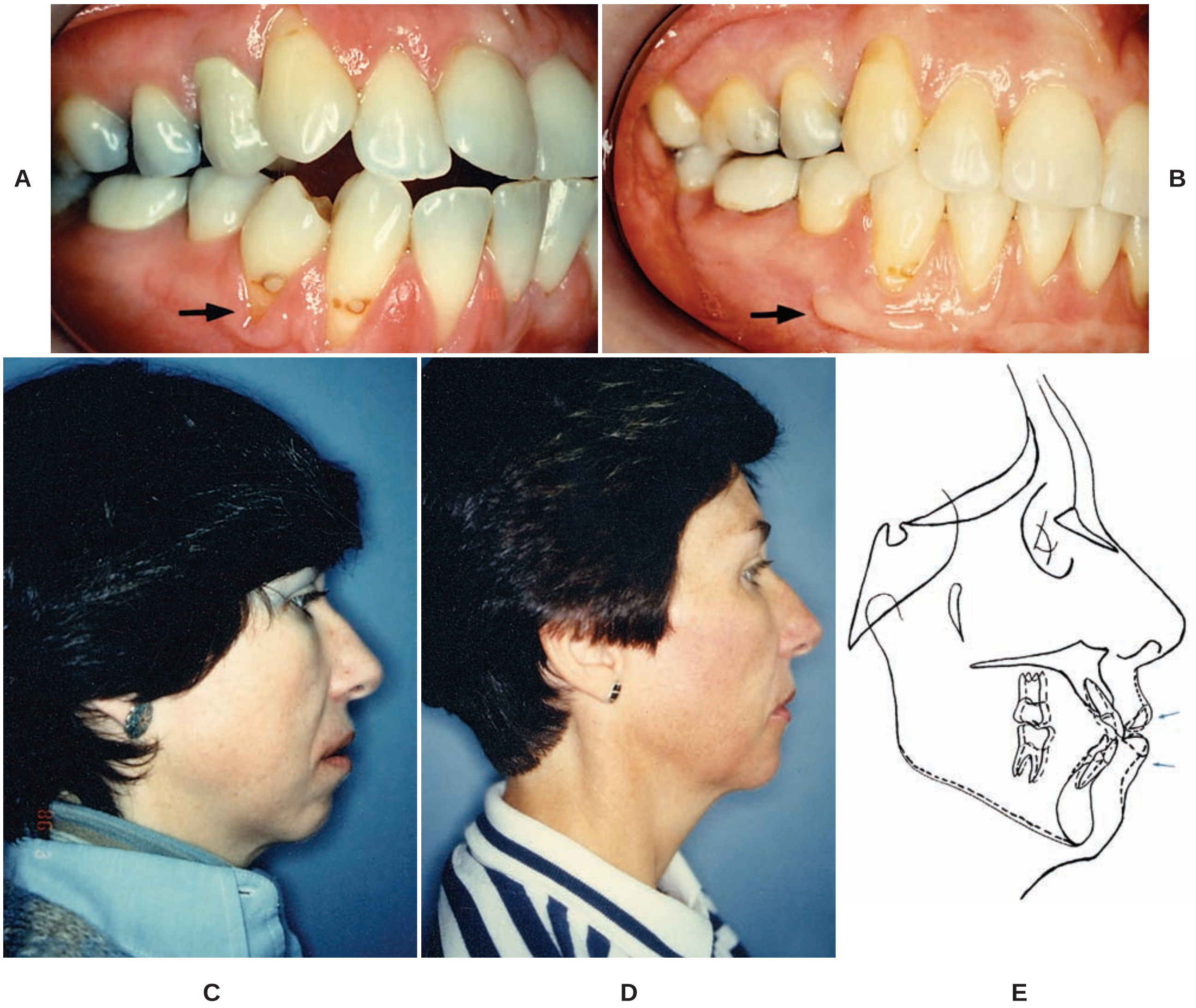
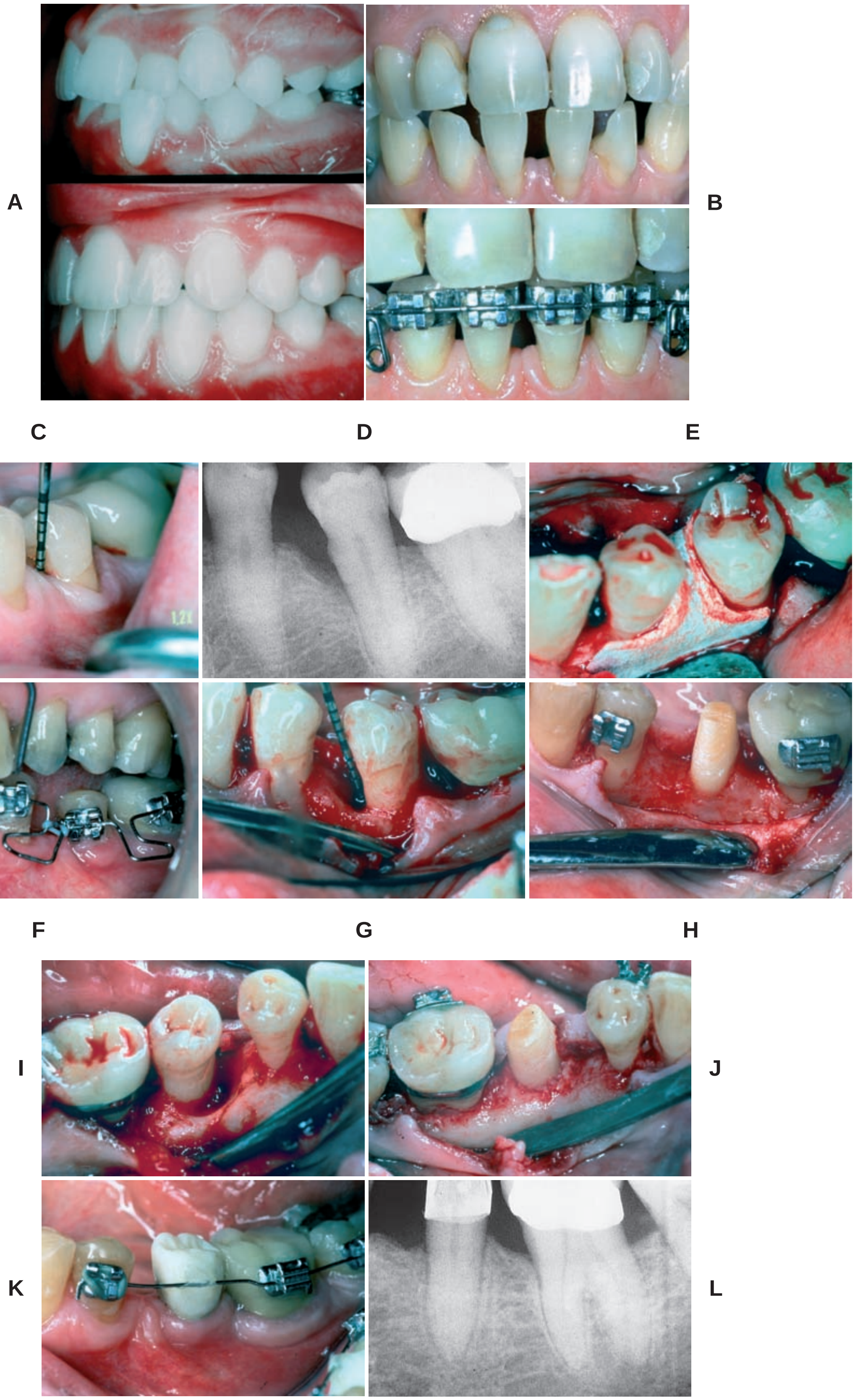


FIGURE 24-10 Clinical example of additional adult orthodontic treatment objective 7: better lip competency and support. **A,** Pretreatment right occlusion illustrating open bite, protrusive upper and lower incisors with crowding and gingival recession (*arrow*). **B,** Posttreatment right occlusion illustrating correction of preexisting malocclusion and incisor retraction with extraction of No. 5, No. 12, No. 21, and No. 28 and correction of gingival recession (*arrow*). **C,** Pretreatment profile showing lip incompetence caused by dentoalveolar protrusion. **D,** Posttreatment profile showing improved lip competence and relaxed mentalis. **E,** Cephalometric superimposition showing corrected incisor protrusion and subsequent lip-position improvement (*arrows*).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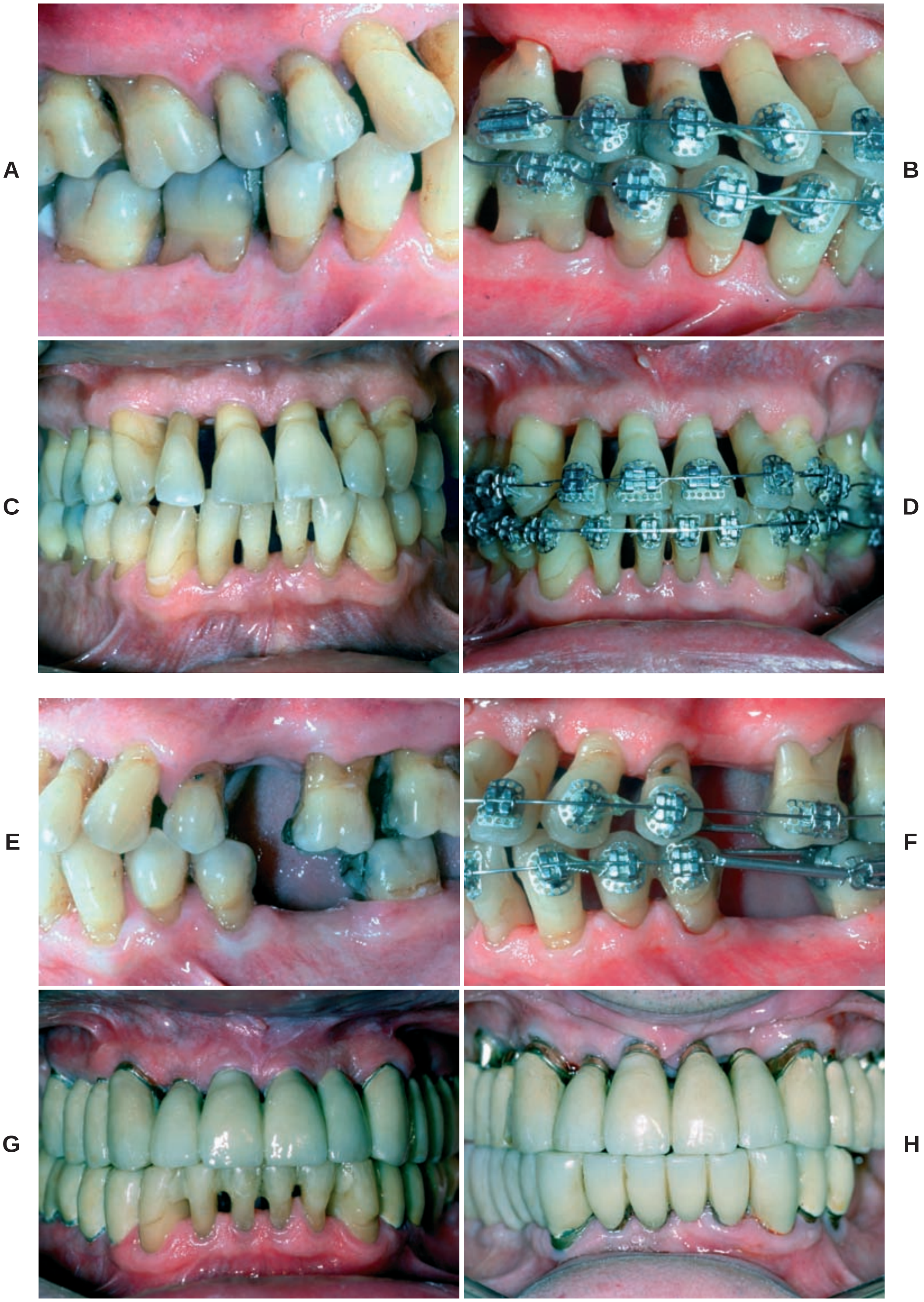


FIGURE 24-12 Clinical example of adult treatment objective 9: improvement or correction of the mucogingival and osseous defects; and adult treatment objective 10: better self-maintenance of periodontal health. **A, C, E,** Gingival form after control of inflammation and occlusal therapy with a bite plane in a 58-year-old man. In patients with posterior bite collapse, the posterior teeth are disarticulated with a Hawley bite plane appliance during scaling and root planing. **B, D, F,** Ahexial positioning of the teeth. Note the changes in gingival form. (The topography improved as the bite collapse was corrected and the teeth were properly positioned.) In addition, controlling gingival inflammation is easier after better tooth position has been established. **G,** Two years posttreatment. **H,** Twenty-two–year follow-up. Patient has maintained his natural teeth.

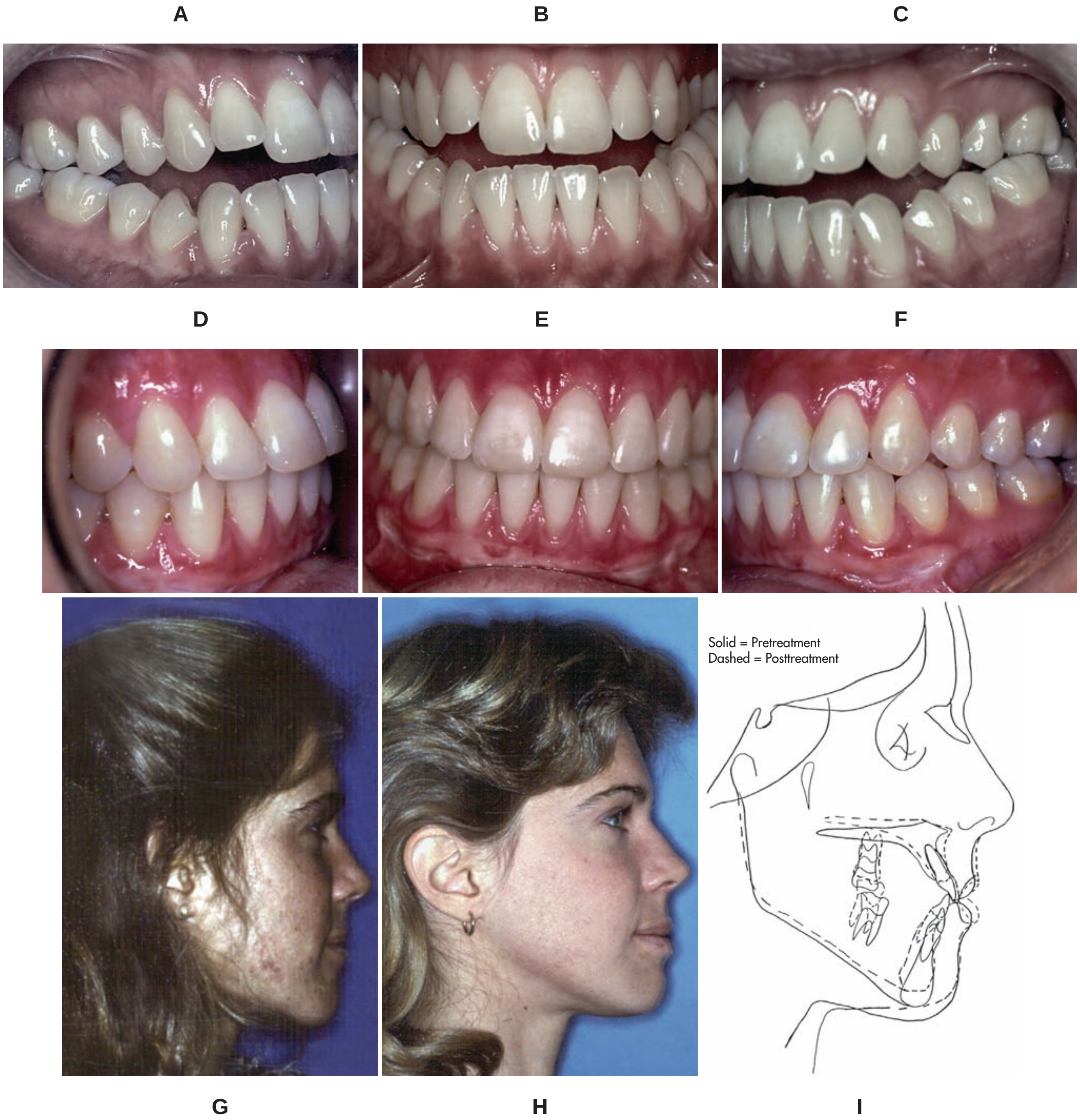


FIGURE 24-13 Clinical example of additional adult orthodontic treatment objective 11: aesthetic and functional improvement. **A–C,** Pretreatment intraoral photographs showing diminished occlusal function because of significant anterior open bite and posterior crossbite. At initial examination, patient had severe temporomandibular joint and myofascial pain because she was forced to "fulcrum" with second molar occlusion. **D–F,** Posttreatment intraoral photographs showing correction of malocclusion through a treatment sequence that included (*1*) splint therapy to improve comfort, (*2*) gingival grafting of lower anterior to protect from further recession, (*3*) orthodontic decompensation and alignment to prepare for jaw surgery, (*4*) orthognathic surgery with maxillary posterior impaction and mandibular auto rotation with mandibular setback, (*5*) completion of orthodontic treatment, and (*6*) stabilization with ongoing nightguard therapy. **G,** Pretreatment profile photograph. **H,** Posttreatment profile photograph illustrating favorable aesthetic improvement that accompanied functional improvement. **I,** Cephalometric superimposition showing overall dental, basal bone, and soft tissue changes that accompanied the interdisciplinary treatment plan. Note that temporomandibular joint and myofascial pain and headaches diminished as functional malocclusal relationships of the masticatory system were corrected.

treatment providers to assess the advantages and disadvantages of each treatment option available. For example, certain borderline skeletal situations can benefit from judicious therapeutic diagnosis that allows the providers and the patient to achieve a result equal to the outcome if jaw surgery were part of the treatment plan (Figure 24-14).

DIAGNOSIS OF ADULT ORTHODONTIC CONDITIONS

The adult patient presents numerous and demanding problems requiring both more specialized data pertinent to the patient's dental and orthodontic problem and a highly skilled mechanism to interpret it. The problem-oriented medical record (POMR) of Weed[18] takes the following into account:

1. Tremendous growth in medical knowledge
2. Resulting increase in specialization
3. Fragmentation of knowledge that has followed this increase
4. Consequential impossibility of relying on memory for adequate patient care

The needs that prompted development of the POMR have also influenced dentistry, particularly adult orthodontics. Figure 24-15 is a synthesized description of the steps necessary to include all variables into the adult patient's treatment planning process. The format and mechanism used for interpreting problems into orthodontic dental records are important steps in improving the practitioner's understanding of the adult patient and in providing treatment measures that can optimize the overall treatment result. Problem-oriented dental records significantly aid in making the appropriate diagnosis because they require that a problem list be developed to manage each problem.[17,18] This is an important improvement over the morphologically oriented diagnostic method that dates from the introduction of Angle's original classification of malocclusion.

A coordinated, logical approach is crucial to successful adult treatment. The following diagnostic steps are recommended.

Skeletal Differential Diagnosis

The correct skeletal differential diagnosis is the key responsibility of the orthodontic member of the interdisciplinary team. Although the lateral cephalogram has been relied on for the skeletal diagnosis in the anteroposterior and vertical planes, the frontal or posteroanterior cephalogram (Figure 24-16) has not been routinely used by orthodontists to make an appropriate three-dimensional diagnosis. It should be noted that in a recent study of *adult patients who sought orthodontic retreatment*, it was reported that about 20% of retreatment adults have a maxillomandibular skeletal discrepancy of 6 mm or greater in the transverse dimension that requires jaw surgery (usually surgically assisted rapid palatal expansion [SARPE]) to achieve an optimal treatment outcome[16] (Figure 25-16).

Diagnoses in the anteroposterior and vertical planes are typically completed using a variety of cephalometric analyses,[21–27] and newer computerized software programs allow cephalograms to be digitized and analyzed allowing an abundant amount of numerical information about the patient's skeletal jaw relations. Frequently, the analyses generate confusing and, at times, conflicting information regarding differential diagnosis of the patient's conditions.

In 1979, Jacobson presented the use of a simplified approach to aid in the diagnosis of skeletal disproportions that might be evident on a patient's lateral cephalogram.[28] This excellent report demonstrated the value of using normative, composite templates to aid in diagnosis and treatment planning. Since that time, two of America's most respected department chairs made statements that validated the use of templates to aid in differential diagnosis. In 1987, Lysle Johnston made the following straightforward statement:

Many clinicians stop tracing cephalograms at about the time their practices start to get busy. Ideally, a descriptive analysis should consist only of those measurements that are needed to illuminate the clinically significant idiosyncrasies of the patient at hand. *Template analysis may seem an ideal solution.*[29]

Proffit pointed out in his 1991 textbook on surgical orthodontics that "the template may appear to be somewhat less scientific than a table of cephalometric measurements with standard deviations, but the template is a *visual analog* of a table and is just as valid." Proffit also states,

> What a template does is place the emphasis on the analysis itself; that is; deciding what the distortions are, rather than on an intermediate measurement step that too often becomes an end in itself rather than just a means to an end.[30]

For the past 30 years, one of the authors of this chapter has used a variation of the Jacobson template method of superimposition; its use has been described as *template-guided diagnosis and treatment planning* (see Figures 25-21 to 25-26). The method that has been described in Chapter 25 of the current text incorporates the following concepts:

1. Standardized templates from the Bolton study provide a composite tracing of proportionate soft and hard tissue that can be of diagnostic value when compared with the patient's cephalometric tracing (for adults, the 18-year-old standard is used).
2. This superimposition technique acknowledges that the size of the patient's nose is a key factor in actual

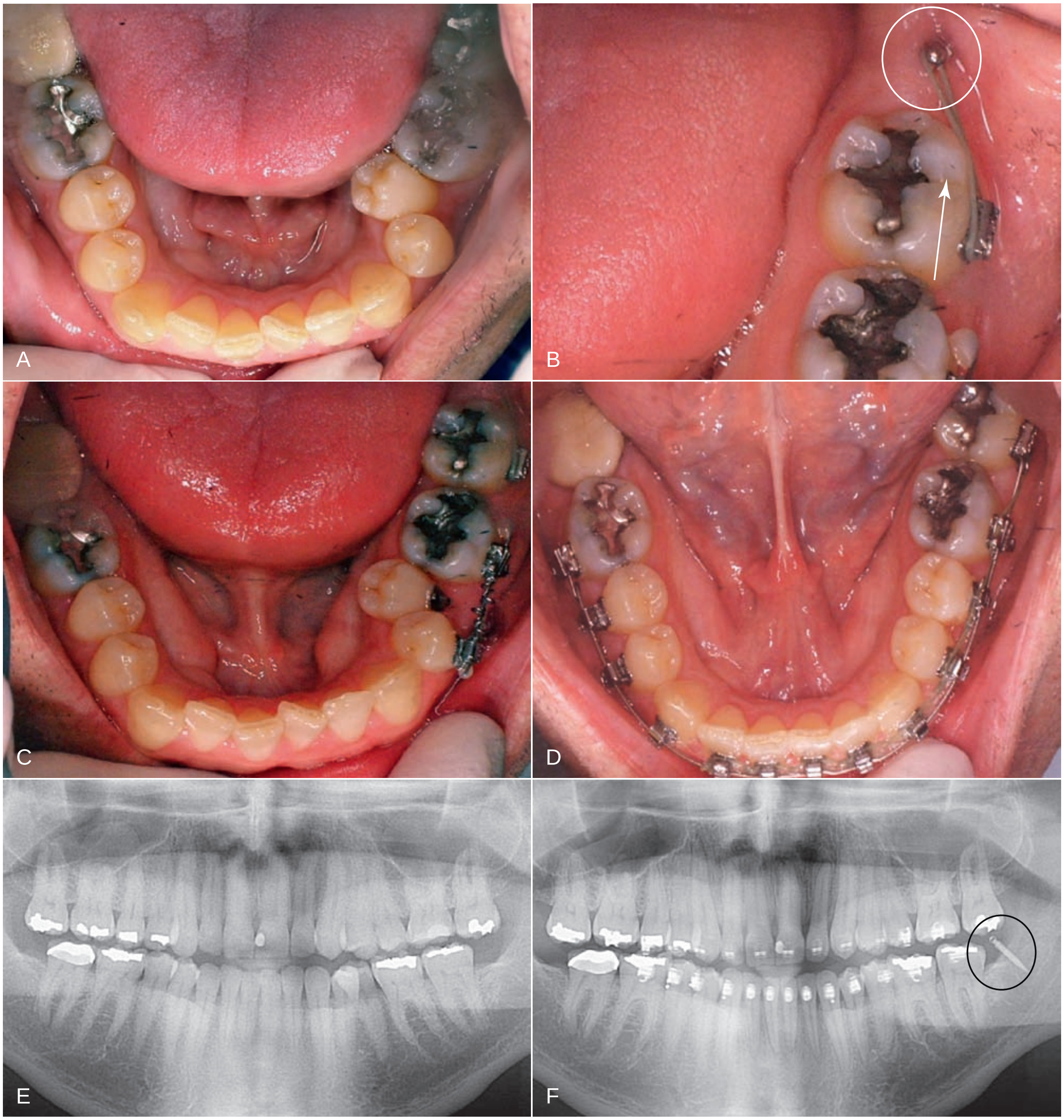


FIGURE 24-14 **A,** Intraoral occlusal photographic view of mandibular arch showing mild anterior crowding and collapse of the arch in the area of #20. One could assume that this arch collapse was a result of early loss of "k" without appropriate space maintenance and subsequent mesial drift of the posterior teeth in that area, disturbing the eruption path of #20. **B,** Close-up occlusal view of that area illustrating a minimally invasive approach using TADS to allow posterior movement (reversal of arch collapse) of #19 and #18 to allow uprighting of #20 and improved axially positioning for better long-term periodontal health in that area (*white circle* at TAD and *white arrow* showing direction of movement). **C,** Lower occlusal view after 4 months of appliance activation. A small amount of room is becoming available for future movement of #20. **D,** Lower occlusal view after 12 months of appliance activation. Mechanotherapy included incorporation of TAD for distal anchorage, open coil spring at area of #20 and light enamel contouring created adequate space for #20 and preserved a healthy, natural dentition. **E,** Pre-treatment panoramic radiograph illustrating the root proximity in the area of the collapse arch at #20. **F,** Progress radiograph illustrating TAD (circle) with favorable molar repositioning due to mechanotherapy described in **D.**

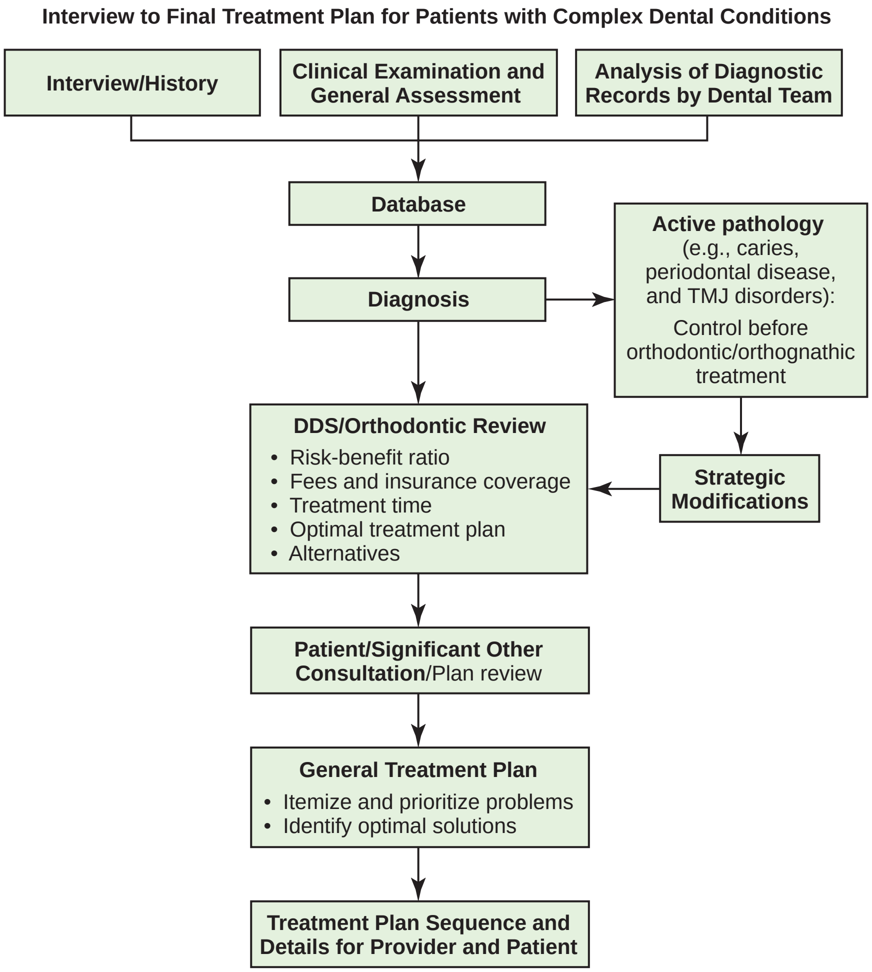

Interview to Final Treatment Plan for Patients with Complex Dental Conditions
Interview/History
Clinical Examination and General Assessment
Analysis of Diagnostic Records by Dental Team
Database
Diagnosis
Active pathology (e.g., caries, periodontal disease, and TMJ disorders): Control before orthodontic/orthognathic treatment
DDS/Orthodontic Review
• Risk-benefit ratio
• Fees and insurance coverage
• Treatment time
• Optimal treatment plan
• Alternatives
Strategic Modifications
Patient/Significant Other Consultation/Plan review
General Treatment Plan
• Itemize and prioritize problems
• Identify optimal solutions
Treatment Plan Sequence and Details for Provider and Patient

FIGURE 24-15 Treatment pathway for adult patients illustrating a *problem-oriented approach* and the decisions that are required to present and to accomplish an optimal treatment plan.

visualized, profile perceptions (e.g., a patient with a large nose and a moderate mandibular deficiency may appear to have a severe mandibular deficiency when viewed in profile because of nasal dominance).

3. The template method described and illustrated thoroughly in Chapter 25 is very "staff and patient friendly" as it allows rapid visualization of the skeletal discrepancy, which helps patients understand why surgical intervention may be needed in a variety of situations.
4. This method is called template-guided diagnosis and treatment planning as it provides an excellent orientation for the clinician to make decisions that will help guide the planning of both the skeletal and dental corrections "in the direction of balanced hard and soft tissue facial proportions" (Figure 24-17).

Periodontal Differential Diagnosis

Periodontally involved or compromised patients who have experienced shifting migration, extrusion, or flaring or lost teeth can benefit from orthodontics designed to correct local causative factors, predisposing malpositions, and certain bony and periodontal pockets.[31,32] Clinical evidence in periodontics shows overwhelmingly that changing local environmental factors can improve periodontal health and reduce the frequency of long-term periodontal maintenance. Orthodontics is one of the most dramatic means available to modify local factors and site specificity of the disease process.

Patients who have already been affected by periodontal disease and have lost significant tooth support are at risk for recurrent episodes of active disease; this group is especially susceptible because of their past history. In the United States, 80% of the elderly have experienced some degree of periodontitis, and 95% of the elderly have moderate to severe periodontal disease. Movement of teeth for periodontally susceptible or previously compromised patients in the presence of inflammation can result in increased loss of attachment and/or irreversible crestal bone loss. Fortunately, research and clinical studies have shown that dentitions with a history of periodontitis or teeth with reduced attachment height

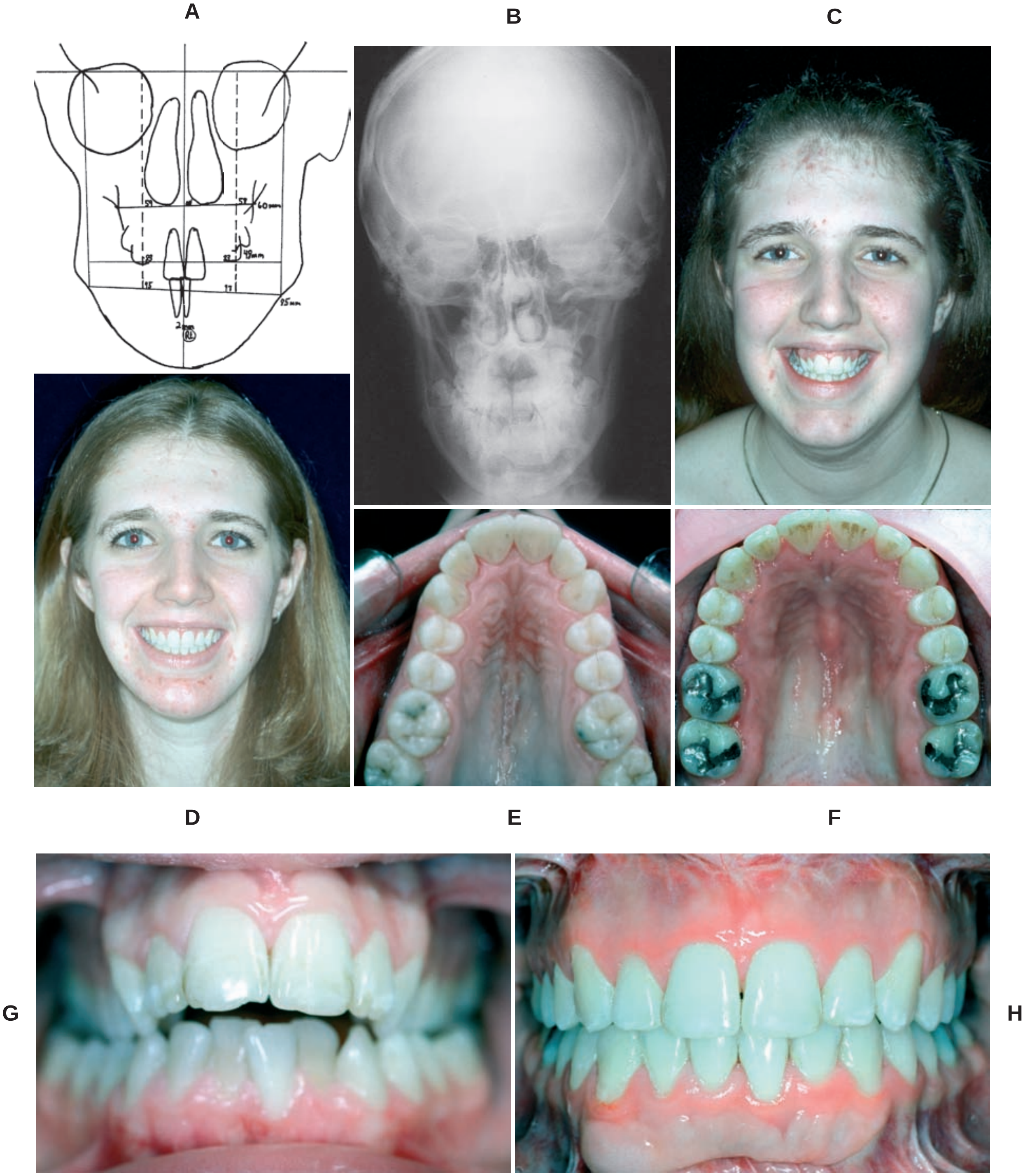


FIGURE 24-16 **A,** Rocky Mountain transverse analysis indicates a mandibular width (GA to AG) of 85 mm and a maxillary width (MX to MX) of 60 mm. The maxillomandibular difference is 25 mm, and the normal for this patient should have been 18 mm. Therefore the expected/actual difference is 7 mm. Surgically assisted rapid palatal expansion may be considered a form of osteodistraction and has been found to be stable if large amounts (greater than 7 mm) of expansion are required. **B,** Pretreatment posteroanterior cephalogram. C–H, Class II, Division 1, 14-year-old white female (skeletal age 17 years), with an A point–nasion–B point angle of 7 degrees, a high mandibular plane, a severe transverse skeletal discrepancy with a differential index of 7.6 mm because of a wide mandible and a narrow maxilla, bilateral posterior crossbites, and 10-mm overjet. **C,** Note the large negative space at the corners of the mouth on pretreatment photograph. **D,** Note the increased buccal tooth visibility and elimination of the negative space after a surgically assisted rapid maxillary expansion to correct the transverse dimension and achieve a natural or broader arch form. **E,** Pretreatment maxillary arch. **F,** Posttreatment natural or broader arch form. **G,** Pretreatment anterior view. **H,** Posttreatment. A second-stage surgery consisted of Le Fort 1 osteotomy with 5 mm of maxillary impaction allowing for mandibular autorotation and a 7-mm advancement genioplasty for profile improvement. Surgically assisted maxillary expansion has been shown to be more stable than two or more segments of Le Fort 1 osteotomy with expansion. Treatment strategy addressed type and magnitude of transverse skeletal deficiency, vertical maxillary excess, growth status, dentofacial aesthetics, stability factors, and periodontal health.

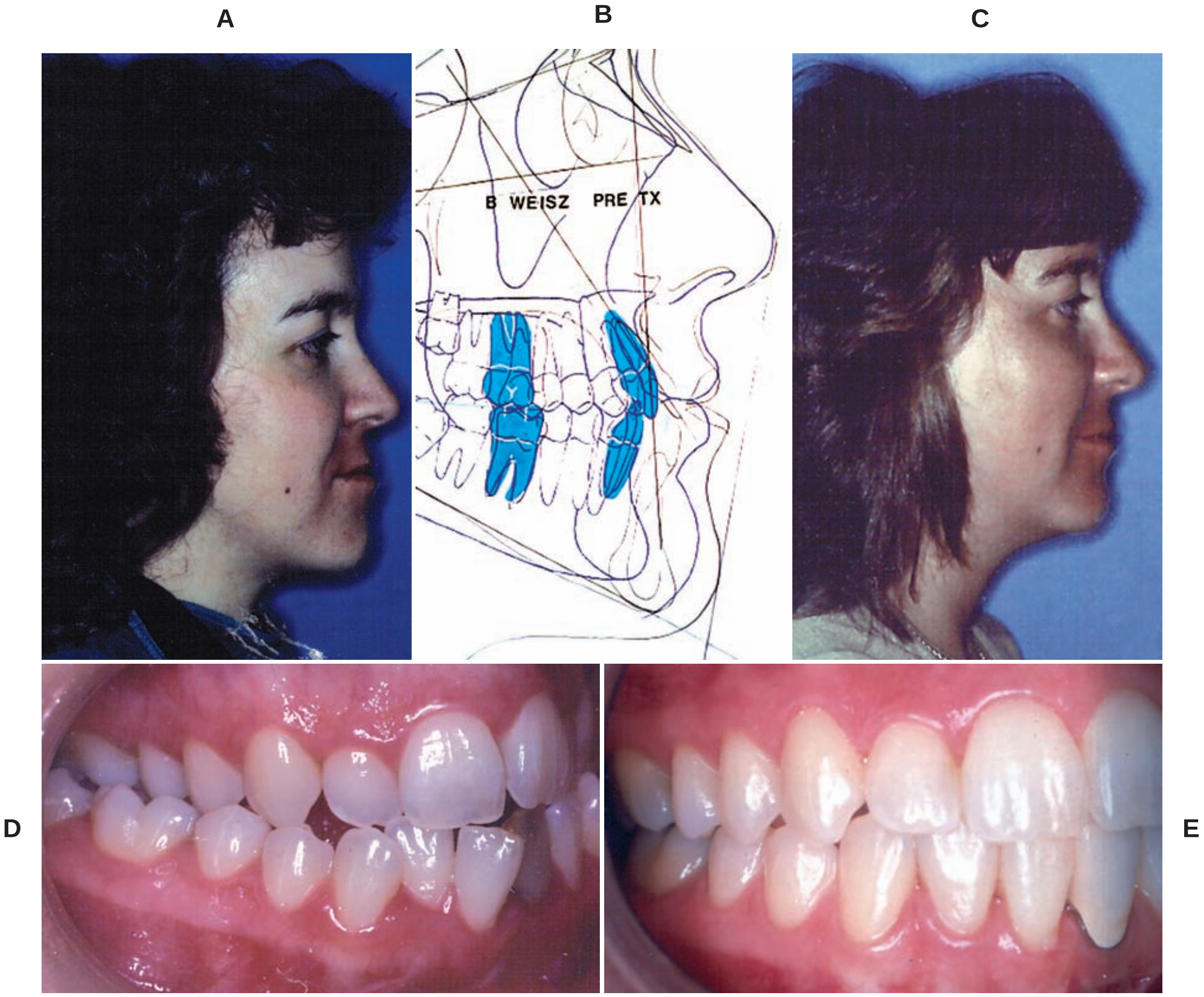


FIGURE 24-17 Differential diagnosis of Class III problem using Bolton template technique to guide the diagnosis and treatment plan. **A,** Pretreatment profile of Class III patient before orthodontic/surgical treatment. **B,** Bolton template (*blue*) superimposed on patient tracing: nasal tip with nasal tip and forehead parallel. **C,** Profile after orthodontics and surgery. **D,** Right occlusion before orthodontic decompensation and surgery. **E,** Right occlusion after orthodontic decompensation and surgery.

can be moved without significant loss of attachment.[33] Identification of the susceptible sites or areas and control of the inflammatory lesion are crucial to successful therapy. All patients, however, will have some degree of inflammation, and it is crucial to ensure that periodontitis remains stable or quiescent throughout orthodontic treatment.

To manage the periodontal issues in adult treatment effectively, the orthodontist must make an accurate assessment of the patient's potential for bone loss or gingival recession during orthodontic tooth movement. A common problem occurs when the orthodontist assumes that the general dentist will provide skilled inflammation control for a patient with incipient periodontal disease. After months of tooth movement and clenching or grinding instigated by movement interferences, dental radiographs may reveal significant bone loss. Consequently, regaining control of periodontal inflammation is harder than controlling it from the beginning. The orthodontist needs to monitor every adult case closely and collaborate with the periodontal specialist to properly treat adult patients. The orthodontist must bear in mind that periodontal disease continues to be an outlandishly large percentage of dental malpractice claims. The basis for the litigation appears to originate from a number of sources:

- Poor case selection
- Poor office procedure in insisting that prospective patients be periodontally stable
- Patient reluctance for or refusal of periodontal checkups
- Dentists' acquiescence in the patient's neglectful behavior
- Ill-defined protocol between orthodontist and general dentist (or periodontist)[34]

Therefore, appropriate management of several factors is needed to prevent negative periodontal sequelae during orthodontic treatment:

1. Awareness and vigilance of the orthodontist and the staff must be heightened.
2. Awareness and vigilance of the patient must be frequently reinforced.
3. Awareness of risk factors related to periodontal breakdown must be understood by and reviewed with the patient (see Chapter 23).

- General factors
  - Family history of premature tooth loss (indication of immune system deficiency in resistance to chronic bacterial infection associated with periodontal disease)
  - General health status and evidence of chronic diseases (e.g., diabetes)
  - Nutritional status
  - Current stress factors
  - Periodontal biotype[35]
  - Life stage of women[36]
- Local factors
  - Tooth alignment, e.g., marginal ridge, cementoenamel junction relationship
  - Plaque indices
  - Occlusal loading
  - Crown-to-root ratio
  - Grinding, clenching habits (parafunctional activity)
  - Restorative status

One of the most overlooked considerations in the management of the adult patient is the impact of patient susceptibility to periodontal disease coupled with the preexisting habit of smoking. Up until 2003, many orthodontists' health history did not include a question on the adult medical history form asking if the patient used tobacco products and a follow-up question about the frequency of use. In 1996, the American Academy of Periodontists published a position paper titled "Tobacco Use and the Periodontal Patient."[37] In this well-researched paper, the American Academy of Periodontists reference 97 published papers that verify the following:

> Clinical and epidemiological studies support the concept that tobacco use is an important variable affecting the prevalence and progression of periodontal diseases, such as adult periodontitis, refractory periodontitis, and ANUG. Several studies have demonstrated that the severity of periodontal disease appears to be related to the duration of the tobacco use, smoking status, and amount of daily tobacco intake.[37]

If there is no health history question regarding tobacco use, and no follow-up in which the patient is informed of the risk of accelerated bone loss and a poor prognosis for long-term health and function, both the patient and the providers could have an undesirable outcome—the patient could because a large investment in his or her dental treatment has high probability of failure, and the providers could because they could be named in legal action for lack of diagnosis and lack of informed consent. The added risk of orthodontic appliances reducing oral hygiene capacity and the "jiggling trauma" of changing tooth positions in a mature neuromuscular environment could lead to rapid periodontal breakdown and blame placed on the orthodontist for "moving the teeth too fast," which hypothetically may lead to expensive restorative procedures and an angry patient.

Temporomandibular Joint Differential Diagnosis

Because the signs and symptoms of TMD often increase in frequency and severity during adult treatment, it is imperative that orthodontists be familiar with their diagnostic and treatment parameters (see Chapter 7). A study by Howard shows that the majority of 3428 TMD patients were between the ages of 15 and 45 (mean age, 32.9 years).[38] However, it is important to note that "craniomandibular disorders are self-limiting, or they fluctuate over time as suggested by declining incidence with age."[39] Unfortunately, knowledge regarding the natural history or course of TMD is limited.[40,41]

In a prevalence study, Schiffman and Friction found that the group of patients whom they treated for TMD problems were divided into several types[42]:

Muscle disorders	23%
Joint disorders	19%
Muscle–joint combinations	27%
Normal	31%

It is important to note that prevalence data frequently overstate the clinical significance of the problem because many patients have mild signs that may be transitory and are better left untreated. The orthodontist treating adults would be wise to have a separate TMD questionnaire to supplement other health history information as part of the initial evaluation process. The goals of such a questionnaire would be to answer the following questions:

1. What type of TMD does the patient have? Muscle, joint, combination, psychosomatic?
2. Where is most of the problem located?
3. Is there pain? What is the degree of pain? What is the frequency of pain? Is the pain chronic or acute? "Chronic pain syndromes are defined as persistent pain that lasts more than 6 months with significant associated behavioral and psychosocial factors."[45]
4. Has there been previous treatment for this problem? What treatment? How long? How effective? Any medication?
5. What is the patient's understanding of his or her condition? Does he or she need a program designed to educate?

FIGURE 24-18 **A–C,** Pretreatment intraoral photographs illustrating previous temporomandibular joint surgery, condyle remodeling, and anterior open bite. **D–F,** Posttreatment intraoral photographs illustrating improved function and bite closure using orthodontics to prepare for surgery, orthognathic surgery, and long-term splint therapy. **G, H,** Pretreatment facial photographs. **I, J,** Posttreatment facial photographs show minimal facial change because of patient's desire to proceed with single-jaw surgery instead of double-jaw surgery. **K, L,** Pretreatment panoramic radiograph and cephalogram. **M, N,** Posttreatment panoramic radiograph and cephalogram. Note that surgery resolved open bite with Le Fort surgery only. Mandibular advancement surgery would have been ideal for profile change but was not used to prioritize reduced risk to fragile and remodeled condyles.

6. Is there an occlusal factor that may be exacerbating the problem? Are there occlusal habits that are known or apparent?

The differential diagnosis may not be established until there are more assessments, records, and imaging. However, the orthodontist must have a clear perspective of diagnostic possibilities. An excellent discussion of TMDs is summarized in Chapter 7.

> Each of these five factors [symptoms, conditions of the dentition, systemic health, aesthetics, and finances] needs to be considered before an appropriate occlusal treatment plan can be developed. It is important to realize that the priority of the factors may be different for the patient and for the therapist. When symptoms are not severe, finances and aesthetics will often be more important concerns of the patient. At the same time, however, the dentist may believe that the condition of the dentition is more important. In any case, the patient's concerns must always remain foremost in the development of a successful treatment plan.[44]

While there is no established *cookbook* for 100% reliability in the management of temporomandibular disorders, Dr. Okeson has presented a series of diagnostic algorithms of appropriate steps in the management of a variety of TMDs.[44]

In summary, the orthodontist treating adults plays a key role in diagnosing a skeletal problem that may require surgery, a periodontal condition that may worsen as a result of tooth movement, and a TMD that requires its own differential diagnosis and plan. *Diagnostic* steps described previously provide an overview to lead the orthodontist and the team of dental providers to a comprehensive *treatment plan* that has the highest probability of achieving the desired *goals* of treatment (Figure 24-18).

CLINICAL MANAGEMENT OF THE INTERDISCIPLINARY ADULT THERAPY PATIENT

Prior to the initiation of treatment for the IAT patient, there are several skills that are required beyond those commonly used in the orthodontic treatment of the child or adolescent patient. Although not every adult patient requires each of the considerations listed next, treatment will progress more easily if the concepts in the section are understood and the orthodontist is already skilled at providing the necessary strategy at the appropriate time.

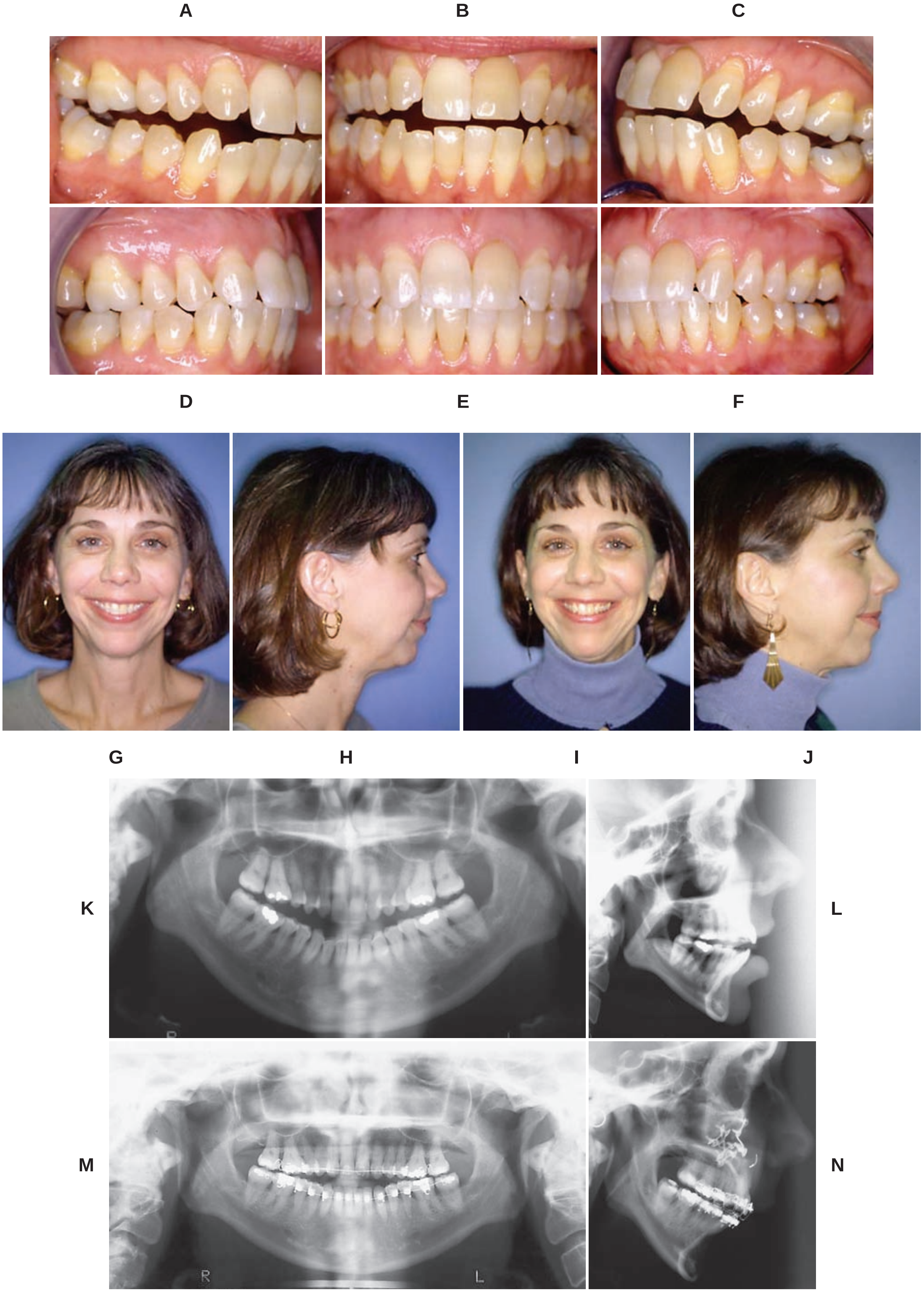
Biomechanical Considerations

Control of Occlusion. There are three crucial ways to control occlusal forces during appliance therapy: disarticulation or disclusion of teeth moved, selective grinding with the high-speed drill, and modification of mechanotherapy for the periodontally susceptible or compromised individual.

Disarticulation. The Hawley bite plane (Figure 24-19) is used for disarticulation (and for diagnosis of TMD patients), to establish centric relation at the acceptable vertical dimension, and as necessary throughout orthodontic treatment to prevent excessive tooth mobility. During the leveling stages, the bite plane is used (in conjunction with posterior sectional archwires) to allow teeth to move free of occlusal forces. The appliance is worn at all times, except while the patient is eating or sleeping. A significant biomechanical advantage of disarticulation (or disclusion) in the adult is that it allows mesially inclined tooth crowns to tip distally to an upright position with only slight mesial movement of their root apices, thereby creating space in the mandible distal to the canines for alignment of crowded lower anterior teeth. If the posterior teeth are not disarticulated, occlusal forces may cause the buccal segment roots to move mesially so that no space is gained distal to the canines during uprighting. Note also that uprighting of posterior teeth, free of occlusal forces, requires much less time and reduces the hazard of mesial root movement and root resorption.

Selective Grinding. The typical adult malocclusion is characterized by posterior teeth that have moved and tipped mesially (accentuated mesial drift) and bite collapse. There is less wear on the mesial marginal ridges than on the distal marginal ridges of mesially inclined posterior teeth. After these teeth start to upright, the mesial marginal ridges need to be reshaped so that the occlusal table will be perpendicular to the long axis of the tooth. Many teeth need to be extruded to correct osseous defects and level the crestal bone but must not be allowed to remain in premature contact after eruption has occurred.

Therefore, at each appointment the bite plane is removed and selective grinding is done as necessary to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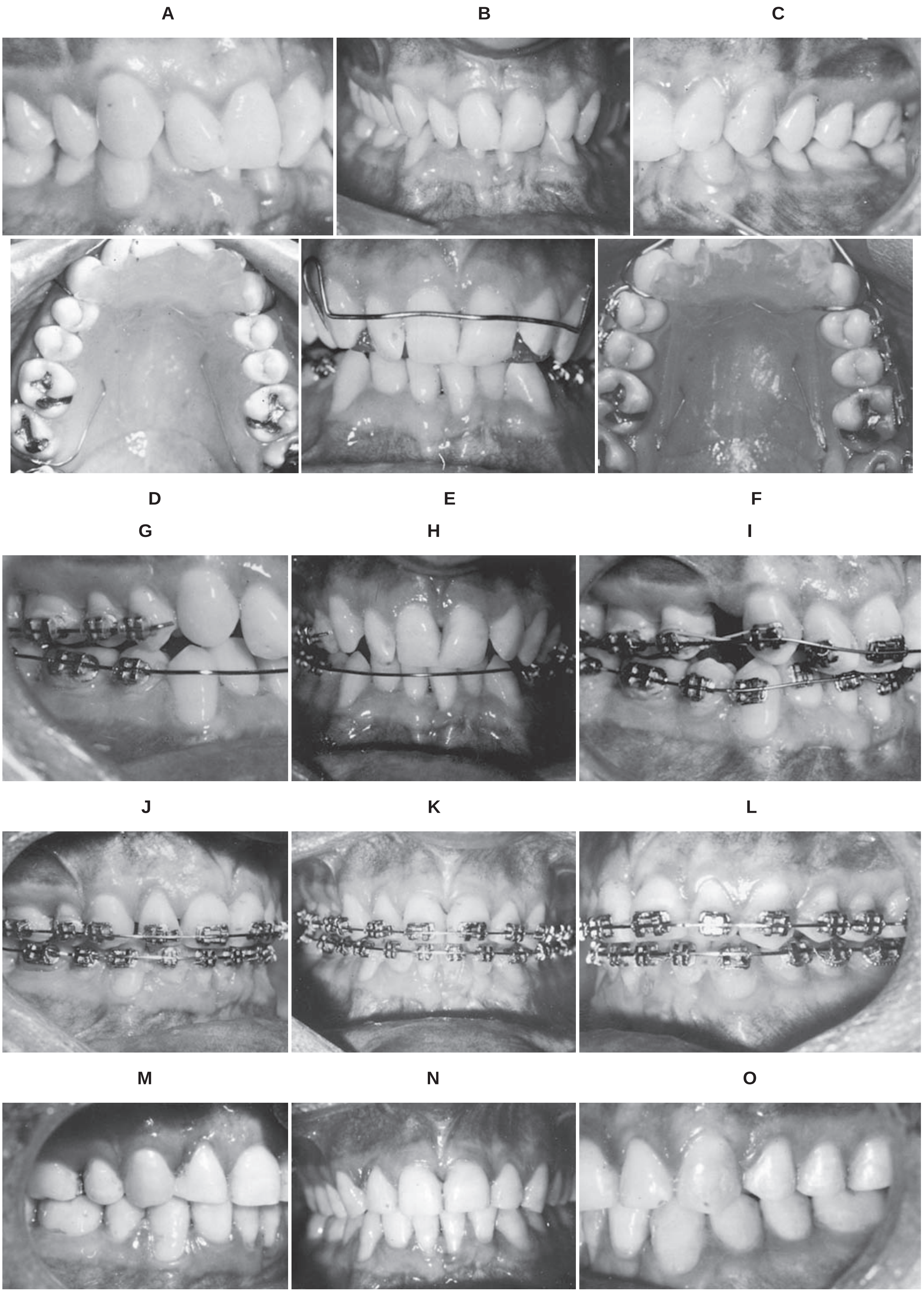
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FIGURE 24-19 **A–C,** Preoperative. Mild Class II skeletal pattern in a 33-year-old man with strong musculature who has experienced some periodontal bone loss. **D,** The Hawley bite plane acts as a diagnostic aid to determine centric relation, control the occlusion during leveling of the posterior segments, and expedite tooth movement. **E,** Lower posterior segments bonded. The bite plane is worn full time (except during eating) to prevent adverse occlusal forces during leveling and alignment of the segments. **F,** Clasps were removed in the maxillary arch. Note that on insertion of the maxillary sectional arches, the acrylic has been cut away 4 to 5 mm from the palatal aspects of the posterior teeth. **G,** Extraction of the maxillary first premolar was delayed until the bite was opened. **H,** The lower anterior teeth, which contact the bite plane, are bypassed by the full lower arch. A full archwire frequently is needed for buccolingual control. **I,** After the posterior teeth are aligned, the premolars are extracted and upper and lower anterior teeth are bonded. The bite plane is discarded, and working mechanics (space closure) are started. **J–L,** Beginning of the finishing and detailing stage. Sequence used in periodontally susceptible adults. **M–O,** Posttreatment.

ensure simultaneous bilateral contact with the posterior teeth when in centric relation. After a malocclusion involving mesially inclined posterior teeth has been uprighted, the posterior segments will not be stable unless selective grinding is used to reshape the occlusal surfaces along with any required operative and restorative dentistry to ensure simultaneous bilateral contact along the long axis when in centric relations. The objectives of selective grinding then are to allow leveling of the attachment to crestal bone and leveling of the marginal ridges to achieve simultaneous bilateral occlusion.

Modification of Mechanotherapy. With traditional multibonded techniques in non–periodontally involved patients, both arches are usually bonded and full continuous archwires are placed. In the adult patient (for reasons stated previously), the authors delay appliance placement on both the maxillary and mandibular anterior segments. This approach is well accepted by adults who invariably prefer no brackets on the anterior teeth during the initial 9 to 12 months that it takes for posterior segments to be axially aligned and for transverse correction to be made (see Figure 24-19) The objective is to set up the posterior occlusion before placing appliances on the anterior segments—these are moved last. After posterior teeth are aligned and axially positioned, the bite plane is removed and the upper and lower anterior teeth are bonded. Space closure is begun and anterior alignment is completed. In Class II cases in which upper premolars may need to be extracted, the extractions can be delayed and then maxillary canines can be immediately retracted into the extraction site, minimizing the time for maxillary space closure. It is more difficult to traumatize posterior segments by parafunctional habits after the teeth have been axially positioned. However, if significant bruxism and clenching during stressful periods cause increased mobility, an immediate impression should be taken for a bite plane. The patient should be given a bite plane for disarticulation and referred for inflammatory control (scaling and root planning) as well. After mobility patterns have been reduced, mechanotherapy can be continued.

Removable Appliances. Within the removable appliance group are appliances designed for both diagnostic purposes and tooth movement. The diagnostic appliances are generally bite places and splints. The acrylic splints are acrylic and wire bite planes with several features that are helpful, depending on the patient's problem. Some of the ways in which these appliances prove useful follow:

- For neuromuscular deprogramming[27,44–46]
- As therapeutic adjuncts to reduce joint inflammation, pain, and parafunction[7,16,47–49]
- As intermediaries during corrective orthodontic therapy to avoid transitory occlusal trauma or treatment-induced TMJ symptoms[24,50–53]

Removable appliances thus serve the patient as a crutch during specific treatment stages. Some patients whose problems cannot be therapeutically resolved without surgery instead will choose to wear a bite plane splint permanently to help maintain a symptom-free joint. Although tooth-movement appliances are in a separate group, on some occasions the appliance can be diagnostic initially and then therapeutic after the diagnostic phase has been completed.

The authors use the following appliances for adults:

- *The sagittal appliance* for distalizing buccal segments or individual teeth, thereby reducing the need for extraoral anchorage (headgear). This type of appliance with a spring-loaded jackscrew is particularly useful for patients who have had maxillary mesial buccal segment drift and thus require distal movement to create or to regain space. Frequently, a bite plane is employed with this appliance to open the bite and allow more rapid distal tooth movement without occlusal or intercuspal intercuspal interference.
- *The slow palatal expander (Schwartz plate)* for mild dental transverse discrepancy cases—This appliance has the potential for addition of an anterior or posterior bite plane to minimize the resistance of occlusal or intercuspal interference during the occlusal correction. Also, bite planes on a palatal expander can deprogram an existing mandibular functional shift. However, skeletal transverse problems in adults resist treatment with this type of appliance and usually

require surgical intervention for a stable correction. The most reliable and stable procedure for correction of maxillary skeletal transverse problems is the SARPE procedure.[54]

- *The phase I appliances* (placed before full appliances) used for reducing the length of time the patient must wear fixed appliances, for testing patient acceptance of the treatment plan, and for initiating tipping movements that may be more efficiently handled by a removable appliance—orthodontists using phase I removable appliances appreciate the rapid tooth movement initiated by them. In addition, the use of this type of appliance frequently provides early insight regarding the patient's degree of motivation that would otherwise be unattainable without a much longer treatment commitment.
- *Bite plane therapy* is used in periodontally susceptible or already compromised bite collapse cases (and for diagnostic aspects in the treatment of TMD patients) and for disarticulation to find the centric relationship at the acceptable vertical dimension—During this phase of treatment an evaluation can be made of the patient's response to the removal of adverse local factors, helping the clinician determine not only the prognosis but also the best therapy for the patient.[51,55]

Preorthodontic inflammation management and occlusal control can be managed by the general dentist or the periodontist, but the orthodontist should monitor this phase and evaluate patient response over time before initiating the orthodontic phase of treatment. In addition, obviously, all caries control should have been completed, overhanging margins corrected, overbulked contacts reduced, irregular marginal ridges reshaped, and endodontic procedures completed.

Fixed Appliances. Accurate predictable interarch and intraarch tooth positioning in most adults requires the use of fixed orthodontic appliances. With continued advancement in bracket design featuring prescribed torque and other angulations, the orthodontist now has the capability of more precise tooth movement with shorter periods of therapy.[56] Advancements in boding techniques, new compositions, and types of fixed appliances have become available, thereby adding to the orthodontist's armamentarium of mechanotherapy options. Pretorqued and preangulated stainless steel labially affixed appliances are described elsewhere in this text and are generally regarded as the most predictable appliances for accomplishing desired tooth movements in all three planes of space. However, plastic brackets, porcelain brackets, mini-brackets such as the Hanson Speed appliance, and lingual or *invisible* appliances have additional appeal to adult patients because of their more cosmetic appearance.

Although plastic and porcelain brackets have cosmetic advantages, they also present significant mechanical disadvantages for certain types of tooth positioning problems. From an analysis of the patient's records, the orthodontist must determine whether the problem is treatable (i.e., treatment goals achievable) within the limitations imposed by the use of cosmetic appliance choices. Recently, claims have been made regarding the effectiveness of a progressive series of plastic *aligners* made from simulated movements on computer-generated models.[27] It remains to be seen whether these appliances can be effectively used in anything other than the correction of problems that require simple tipping. The initial choice of appliances can be altered during treatment, but it is wise nonetheless to provide for an alternative treatment plan (and appliances if needed) that will accomplish the treatment goals efficiently and predictably, especially when treating adults whose expectations of treatment may be extremely high.

Use of Temporary Anchorage Devices (TADs). Mini-screw implants for orthodontic anchorage have become a useful clinical tool that can simplify orthodontic treatment. Tooth movement that has been considered beyond ordinary mechanotherapy (asymmetric extractions, bimaxillary protrusions, molar intrusions, distalization, mesialization, etc.) can be achieved with minimal patient cooperation with the use of mini-screws (see Chapter 12).

Orthognathic surgery may not be needed in certain open bite and bimaxillary protrusion cases. Patients may be presented with an option other than orthognathic surgery.

Occlusal Control. Occlusal control during the leveling phase of treatment in advanced cases can be accomplished with the aid of the Hawley bite plane and posterior sectional arches (see Figure 24-8). To prevent excessive forces from bruxism and clenching, it may also be necessary to insert bite planes during stressful periods throughout the course of orthodontic care.[48] Fortunately, after the posterior segments have been axially positioned and the transverse correction made, it is more difficult for the patient to traumatize posterior segments by parafunctional habits.

Periodontal Accelerated Osteogenic Orthodontics. Periodontally accelerated osteogenic orthodontic (PAOO) technique has been suggested to enhance orthodontic treatment by acceleration of treatment, better stability, and improvement of the periodontium.[57] Some cases are reported in Chapter 23.

Periodontal Management during the Orthodontic Tooth Movement

Patients who have already been affected by periodontal disease and have lost significant tooth support are at risk for recurrent episodes of active disease; this group is especially susceptible because of their past history. In the United States, 80% of adults have experienced some degree of periodontitis, and 95% of the elderly have moderate to severe periodontal disease.[58] Movement of teeth for periodontally susceptible or previously compromised patients in the presence of inflammation can result in increased loss of attachment and/or irreversible crestal bone loss. Fortunately, research and clinical studies have shown that dentitions with a history of periodontitis or teeth with reduced attachment height can be moved without significant loss of attachment.[59] Identification of the susceptible sites or areas and control of the inflammatory lesion are crucial to successful therapy. All patients, however, will have some degree of inflammation, and it is crucial to ensure that periodontitis remains stable or quiescent throughout orthodontic treatment.

Significance of Tooth Mobility. Many experimental studies have demonstrated that traumatic lesions in the presence of a healthy periodontium do not initiate loss of attachment or periodontitis. Investigations using beagles[104] and monkeys[60] have improved our understanding of the relationship between inflammation and occlusal trauma.

Studies in the beagle by Svanberg have shown that trauma from occlusion that had created increased tooth mobility can also cause increased vascularity, increased vascular permeability, and increased osteoclastic activity during a traumatic phase lasting approximately 60 days.[61,62] After a stable, permanent hypermobility was established, vascularity and osteoclastic activity returned to normal. These findings led Svanberg to suggest that only through measurements taken at intervals can one determine the existence of progressively increasing mobility that may be diagnosed as trauma from occlusion. Jiggling occlusal forces have been found to aggravate active periodontitis, accelerate loss of connective tissue attachment, and possibly diminish gain in reattachment after periodontal treatment.[63,64] A study evaluating the association between trauma from occlusion and severity of periodontitis concluded that teeth with increased mobility have greater pocket depths and less bone support that teeth without these findings.[65] A University of Pennsylvania study evaluated initial alignment and level of teeth and also determined the effect of probing depths on healthy teeth.[34] The results indicated that test teeth in this study did not show significant change (i.e., the increase in the plaque or sulcular bleeding indices between the initial appointment and the appointment at which maximal tooth mobility was recorded) to ensure that any increase in probing depth could not be caused by increased periodontal inflammation. Eleven patients served as their own controls. The test teeth that became mobile demonstrated an increase in probing depth by an average of 1.09 ± 0.53 mm between the initial appointment and the appointment at which the maximal tooth mobility value was recorded. Therefore, it was concluded that during orthodontic alignment and leveling, teeth with significant increase in mobility will also have an increase in probing depth and that severely rotated teeth will have a greater increase in mobility.

The findings of this preliminary study indicate that increased tooth mobility has a detrimental effect on the periodontium and that increased probing depth indicates an increased periodontal risk such as an increase in the patient's susceptibility to periodontal disease. Therefore, subgingival microbiota should be removed during periods of increased mobility, and appropriate steps should be taken to prevent further tooth mobility in patients who have already demonstrated periodontal susceptibility.

Periodontal Preparation of Adults before Orthodontic Therapy. Successful adult orthodontic treatment for many patients will depend on the periodontal preparation before treatment and the maintenance of periodontal health throughout all phases of mechanotherapy. Gingival inflammation must be eliminated by acceptable oral hygiene measures and removal of accretions on the teeth (usually by scaling and root planning). The occlusion also must be controlled during periods of stress and severe bruxism throughout orthodontic treatment so that occlusal trauma[52,66] and excessive tooth mobility will be prevented.[67] The Hawley bite plane is used for disarticulation as necessary throughout treatment (see Figure 24-19).

Smoking Cessation. Oral health providers can have a significant impact on patient tobacco cessation. Established tobacco intervention protocols, such as those advocated by the National Cancer Institute, can be easily applied in the clinical setting. Providers should apply the 6 A's :

Ask—Systematically identify all tobacco users at every visit.

Advise—Strongly urge tobacco users to quit. Advice should be clear, direct, and personalized for each patient.

Assess—Determine willingness to make a quit attempt.

Assist—Aid the patient in quitting. Tell the patient to remove tobacco products from their environment and to avoid situational cues, such as alcohol consumption or socializing with active smokers, which may facilitate unplanned relapse.

Arrange—Schedule follow-up contact. Follow-up contact should occur soon after the quite date, preferably during the first week. A second follow-up contact is recommended within the first month. Schedule further follow-up contacts as indicated.

Actions during follow-up—Congratulate success (if tobacco reuse has occurred, review circumstances and elicit recommitment to total abstinence). Remind the patient that a lapse can be used as a learning experience. Identify problems already encountered and anticipate challenges in the immediate future. Assess pharmacotherapy use and problems. Consider use or referral to more intensive treatment.[57,68–74]

Gingival Tissue. The orthodontist should make a clinical distinction between thin delicate gingival tissue and normal or thickened tissue that is in the labiolingual plane.[75,76] The thin, friable tissue is more prone to undergo recession during orthodontics than normal or thick tissue (see Chapter 23).

In addition, if a minimal zone of attached gingival exists, particularly on abutment teeth, it is prudent to place free gingival grafts to help control inflammation before orthodontic treatment begins. It is important to note that the orthodontist *controls the timing* of referral for grafting procedures. The prognosis for successful gingival grafts and prevention of bone loss is better if these are done before any recession has taken place.

Osseous Surgery. As a rule, orthodontics should logically precede definitive osseous surgery. The optimal approach is as follows: (1) complete the orthodontic therapy, (2) establish a stable occlusion, and (3) wait a minimum of 6 months before requesting the periodontist to intervene for definitive periodontal procedures.

Inflammation Control. Several visits with a periodontist or hygienist will not suffice to prepare a periodontally compromised adult properly for orthodontic correction. Meticulous root surface preparation and curettage are required. In patients with significant bone loss, furcation involvement, and severe pocket depths, it may be necessary for the periodontist to perform open-flap procedures[77] for removal of diseased gingival tissue and proper root surface preparation before orthodontic therapy. Better visualization and access may allow deeper pocket areas and tortuous root configurations to be root planed properly. Before open-flap debridement in cases with advanced periodontal disease, control of adverse occlusal factors using the Hawley bite plane is essential.

Gingival bleeding provides the most reliable index for determining the presence of clinically significant gingivitis,[78] and before placement of appliances no significant gingival bleeding should occur on gentle probing.

Healthy tissue will not bleed when a thin Michigan probe is gently inserted into the sulcus. To keep the patient free of inflammation during treatment, root planning and curettage should be scheduled as frequently as necessary to prevent significant bleeding. Also, to assess disease activity, the tendency to bleed should be evaluated at each appointment. If this inflammation control is not rigidly adhered to, irreversible bone loss will inevitably result in the periodontally susceptible patient.

Behavioral Management Orthodontist and Staff Preparation for Adult Interdisciplinary Patient Management

Adult patients present an ongoing challenge before, during, and after the prescribed treatment. To meet this challenge and improve the quality of care for each patient, orthodontists treating adults should integrate several steps in the areas of behavioral and clinical management into their professional activities.[79]

1. **Advanced continuing education courses**

   Because a larger percentage of adult patients (1) have conditions that require interdisciplinary therapy and (2) require treatment in areas of the emerging knowledge, it is helpful to seek continuing education that provides an opportunity to update the orthodontic clinician's knowledge and skills in the specialty areas of periodontics, orthognathic surgery, TMD management, and restorative dentistry. In addition, opportunities exist to play an efficient role in the delivery of care.

2. **Refined consultation techniques**

   Methods of consultation or case presentation vary from orthodontist to orthodontist.[80,81] When reviewing records with the adult, particularly patients who require interdisciplinary dental therapy (60% to 70%), it is valuable to employ a consultation format designed to inform and educate. For patients with tooth size discrepancies, borderline or atypical extraction problems, restorative uncertainties, or some unique surgical situations, using a diagnostic setup on mounted models is usually informative and sometimes quite revealing to both the orthodontist and the patient.

   For cephalometric analysis of the patient with a skeletal disharmony, the Broadbent-Bolton transparencies or the Jacobson templates are helpful. They have proved to be graphic tools enabling the orthodontist to translate cephalometric data into a visually understandable reference for the patient who is considering orthodontics and orthognathic surgery (Figures 24-20 and 24-21).

   Also, the chart enables orthodontic-orthognathic patients to consider anticipated changes resulting from combined therapy in a more informed way. The skeletal disharmony patient, particularly one with a borderline skeletal-dental problem, requires a clearer explanation regarding therapeutic alternatives than do many other patients.[82,83]

   Educating and informing the patient about the presence and significance of moderate or advanced periodontal disease can be a delicate process if the referring dentist has not discussed this with the patient.[84–86]

   Frequently the orthodontist's hygienist may have made the patient aware of the existence of this problem at the initial examination. The orthodontist will then be in a better position to refer the patient to a periodontist for needed therapy. A recent publication provides excellent schematics that help to educate patients.[87]

   Other innovative consultation devices (i.e., a *before and after* photographic bulletin board, videotaped interviews with similarly treated adults) can greatly enhance the patient's knowledge and confidence.

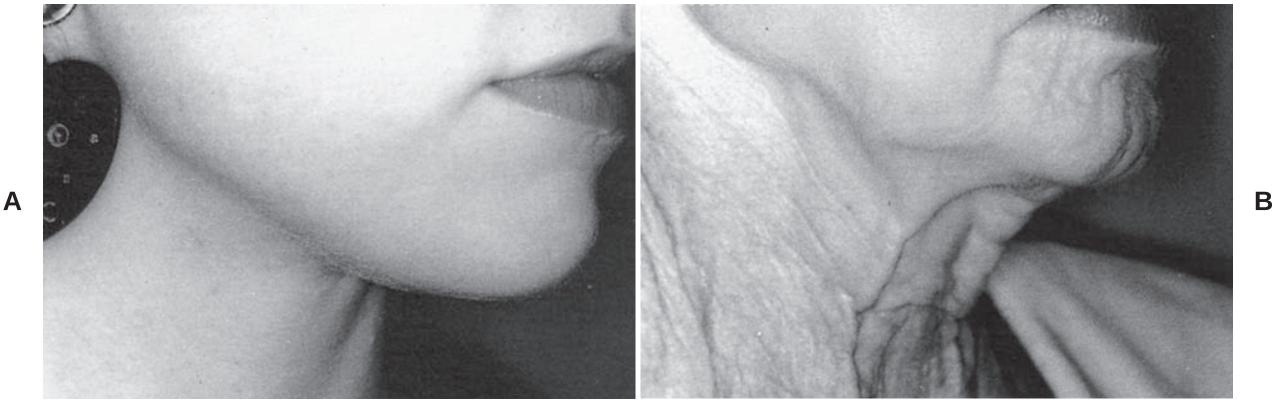

FIGURE 24-20 **A,** Youthful appearance has a well-defined mandibular line and good definition between face and neck. **B,** The aged face has a less-defined mandibular line and lack of definition between face and neck. (From Koury ME, Epker BN: The aged face: the facial manifestations of aging, *Int J Adult Orthod Orthognath Surg* 6(2):81–95, 1991.)

Grateful patients, who have successfully undergone complex treatment, will often provide a reassuring person-to-person consultation with a prospective patient regarding their own experiences with a proposed treatment modality. This is a frequently used educational procedure for patients who are considering orthognathic surgery. A patient who has already received the projected care is uniquely qualified to fill any knowledge voids, especially in areas of family care and inconvenience, work interference, rate of recovery, and pain and discomfort. Finally, adult patients who are about to undergo multidisciplinary therapy seem to appreciate dual or multispecialist consultation so that all questions and information exchanges can be addressed on one occasion, thereby increasing patient trust regarding a shared level of agreement and permitting unanimous approval and understanding of upcoming treatment.[39] Dual or multispecialist consultations also aid in organizing the timing and sequencing of steps needed to complete the planned therapy.

3. **Appliance modifications for adult treatment to reduce concern about appearance**[6,76,88]

Numerous appliances are available to provide for tooth movement within a biologically sound range. Two basic appliances, removable and fixed, are widely used. Within the categories are a multitude of choices, and it is logical that each orthodontist will employ the one that is both comfortable for the patient and reliable in accomplishing the desired treatment goals.[89]

Key elements of diagnosis and patient preparation have been discussed in this chapter thus far. Incorporation of the skeletal diagnosis, periodontal assessment, and TMJ management lead to the treatment plan and to patient education. Once these steps have been taken, the adult interdisciplinary team and the patient should be ready to identify the specific sequence of steps that need to be taken to create a balanced occlusion, with healthy supporting tissue, harmonious facial proportions, and restorations to repair damaged or lost teeth.

SEQUENCE OF ADULT INTERDISCIPLINARY THERAPY

As has been discussed, the diagnostic considerations are more complex for the AIT patient, and the treatment planning decisions vary greatly between adults and their adolescent counterparts. Many points discussed in the previous two sections may seem self-evident to the practicing orthodontist, but while they may be self-evident, it must be emphasized that it is the orthodontist who is frequently placed in the position of treatment plan director. For example, decisions regarding extraction/nonextraction and surgery to correct or tooth movement to camouflage skeletal problems are key orthodontic responsibilities. Along with these decisions, the orthodontist, as treatment plan director, must establish the sequence of implementing the treatment plan—who does what when, and how does the orthodontist communicate the sequence and the rationale of the sequence to the patient and to the other providers for their input and modification? The written sequence then becomes the blueprint for the restoration of the skeletally and dentally imbalanced, diseased, mutilated, and/or worn stomathognathic system.

An important advantage of categorizing patients into *provider* groups is in the area of patient education, particularly as it relates to sequence of treatment. After the diagnostic process, the practitioners involved must be precise in outlining the steps of treatment and the rationale for these steps to their patients. Patients under dual provider and multiple provider care must also be educated to the plateaus of treatment progress and how these relate to their well-being.[5]

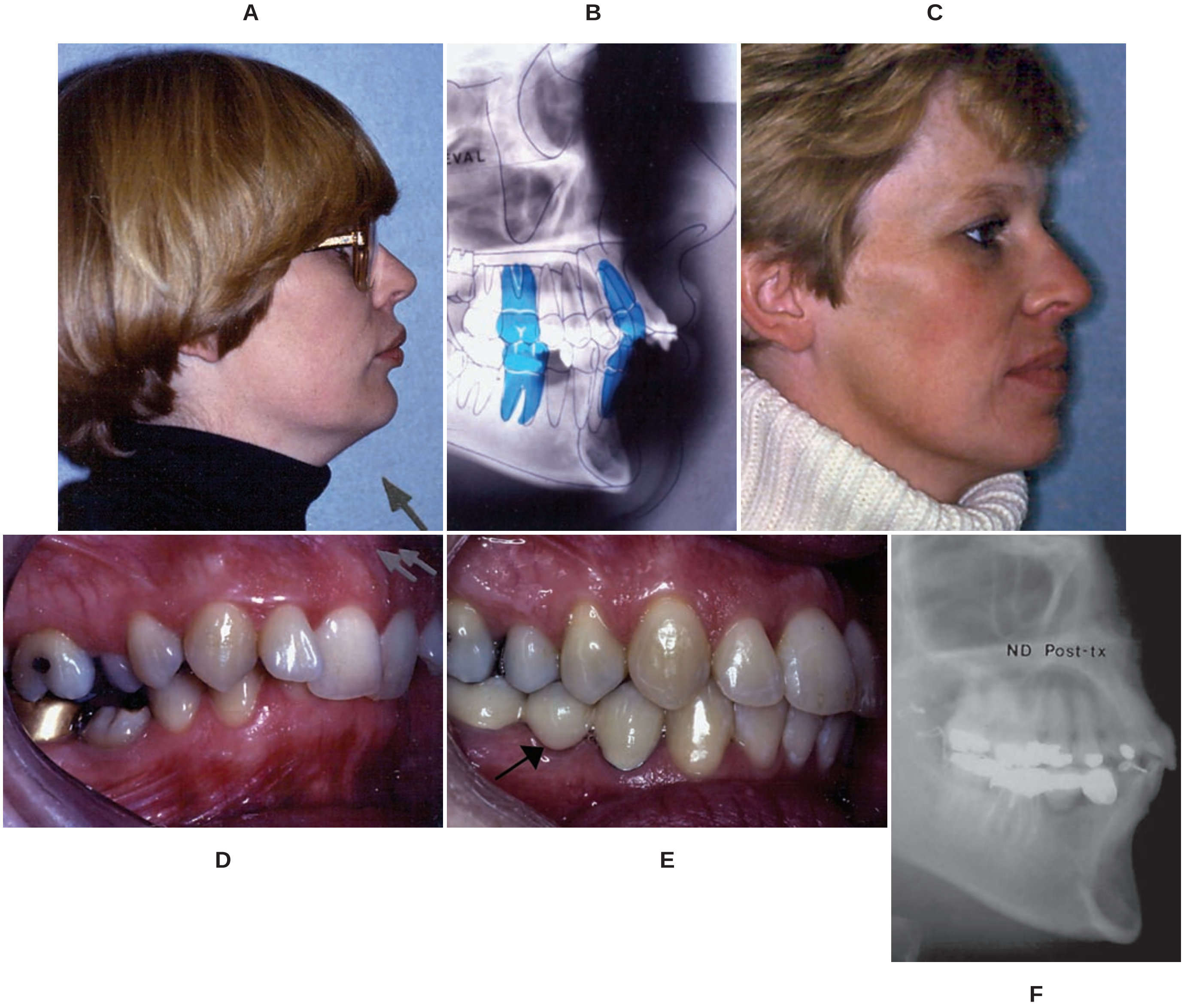

FIGURE 24-21 **A,** Profile photograph taken after preliminary leveling (same as cephalogram in **B**). Evidence of maxillary dentoalveolar protrusion and mandibular deficiency is apparent. Two different treatment plans make sense: the one chosen will depend on what goals are prioritized. The *arrow* illustrates "youthful" throat-chin soft tissue contour. **B,** Cephalogram after 4 months of incisor reangulation (decompensation) to allow reassessment of treatment plan using Bolton template to guide decision regarding extraction of upper first premolars and camouflage of moderate mandibular deficiency or "slow aging" of lower third of face by correction of mandibular deficiency with mandibular advancement. **C,** Profile photograph taken after orthodontic treatment and mandibular advancement surgery. Although a camouflage treatment plan would have worked, the patient indicated the importance of chin position improvement. The Bolton template superimposition guided the treatment plan and indicated that mandibular advancement would be appropriate based on landmark comparison to the proportionate facial guidelines of the superimposed template. **D,** Pretreatment right occlusion illustrating anterior crowding, retroinclined maxillary incisors, deep bite, retained deciduous right mandibular second molar, and a Class II, Division 2 malocclusion. **E,** Posttreatment comparing right occlusion with **D.** The patient desired to position her chin more forward to avoid the potential "aging effects of chin deficiency," which the patient observed as her mother aged. **F,** The patient chose a conventional bridge to replace the missing lower right second premolar shown with an *arrow* in **E.**

1. Active disease
2. Disease arrested
3. Disease controlled
4. Contributing structural malrelationships corrected
5. Periodontal defects corrected
6. Restorative and reconstructive dentistry completed
7. Optimal oral health maintained

Failure to adequately educate patients in this area will result in high rates of noncompliance and potential litigious action. Informed consent is essential.

Skeletal Evaluation

One of the first questions that must be asked to determine the sequence of AIT is, "Does the skeletal problem require surgical intervention to create a stable correction?" Patients with skeletal imbalances who plan to undergo orthognathic procedures require our utmost attention and care (see Chapter 25). Although they have the potential to receive the greatest benefits from combined therapy, they also are exposed to the greatest risk. Each step in this outline (see Box 25-2) is essential for consistent success and quality outcomes. Note: Step 16 in the Sequence, posttreatment (6 to 12 months) records, is often skipped. However, it is crucial for refinement and improvement of future team efforts. This step can become an important *in-house* approach to the team's continuing education protocol.

Interdisciplinary adult patients require treatment sequencing information, as outlined below, so that standardized communication of the treatment plan is available to the patient and all providers.

The key elements are as follows (see Figure 24-15):

- Orthodontic diagnosis
- List of dental problems
- Sequence of treatment to manage problems
- Rating of severity
- Rating of prognosis with treatment (include a discussion of limiting factors)
- Addressing patient concerns

Periodontal Preparation

Does the periodontal problem require intervention to create a stable correction? One of the most frequently overlooked aspects of orthodontic treatment for adults is the patient's level of periodontal health before the placement of fixed orthodontic appliances. Frequently, the orthodontist is responsible for determining the level of periodontal health so that thorough measures can be undertaken to stop the advancement of periodontal destruction during tooth movement.

For the orthodontist, the periodontal health of adult patients may be classified in one of three categories: incipient periodontal disease, moderate periodontal disease, or advanced periodontal disease. Each level of periodontal disease requires different therapy with consistent monitoring throughout fixed mechanotherapy to ensure the disease is arrested and inflammation is controlled.[78,90] Careful compliance with these steps will help ensure no loss of the supporting alveolar bone during orthodontic treatment.

Although various types of procedures have been recommended to control periodontal disease, it should be remembered that conservative approaches are effective in the treatment of cooperative patients with periodontal disease, and no orthodontic appliances should be applied to patients who are undergoing periodontal treatment. Adult orthodontic patients generally have 12 to 30 months of fixed appliance therapy, and these appliances interfere with *convenient* oral physiotherapy with the additional potential negative effects of iatrogenic transitional occlusal trauma induced during certain states of orthodontic tooth movement.

Before beginning tooth movement, inflammation should be reduced by root planning and curettage. As previously pointed out in Chapter 23, it may be necessary to perform open-flap curettage for direct visualization. All members of the interdisciplinary dental team must accept responsibility for adequate oral physiotherapy and mechanical maintenance of gingival health in deep pocket areas. This is achieved by root planning, tooth polishing, and curettage throughout tooth movement as frequently as necessary to keep the periodontium free of significant inflammation. Bleeding on gentle instrumentation or problem is the most reliable clinical indication of inflammation. If, during curettage, blood pools in the gingival margin surrounding a tooth, too much inflammation will be present to perform tooth movement for a periodontally susceptible patient. The frequency of visits during tooth movement will be determined not by orthodontic adjustments but by the necessity to control soft tissue inflammation during appliance therapy. This could become a biweekly basis in the 60- to 70-year-old patient. A periodontally susceptible patient should never be placed on an automatic 2- to 3-month recall program for removal of subgingival microbiota, as has been suggested in the literature.[91] Periodontally susceptible patients who are undergoing orthodontic treatment may have very rapid repopulation of the gingival bacteria and require appointment-to-appointment monitoring.

Periodontally involved or compromised patients who have experienced shifting migration, extrusion, flaring, or lost teeth can benefit from orthodontics designed to correct local causative factors, predisposing malpositions, and certain bony and periodontal pockets.[31] Clinical evidence in periodontics shows overwhelmingly that changing local environmental factors can improve periodontal health and reduce the frequency of long-term periodontal maintenance. Orthodontics is one of the most dramatic means available to modify local factors and site specificity of the disease process.

DENTOALVEOLAR COLLAPSE: ORTHODONTIC AND RESTORATIVE CONSIDERATIONS IN THE ADULT INTERDISCIPLINARY PATIENT

Because alveolar and basal bone are fundamental to successful oral health, it is not surprising that any new findings regarding bone healing and bone remodeling would be important dental specialists. This interest becomes particularly true with increased number of aging patients who seek oral rehabilitation. The recent study by Osterberg and Carlsson[91a] found that as fixed partial denture technology improved, so also did patients desire for implant restoration as part of oral rehabilitation. Before the reported success and acceptance of the Branemark system of dental implants in the 1980s, oral rehabilitation was a very complicated process incorporating the principles of perioprosthetics that were well documented by Morton Amsterdam in 1974.[11]

In 1974 when very sophisticated perioprosthetics was required to provide fixed restorations to avoid removable dentures, dentists were reminded of the role that orthodontics can play in optimizing the restorative outcome. "It should be noted that when an orthodontic malocclusion also exists in the presence of disease, more frequently than not, it will be necessary to correct or modify those functional aspects of the malocclusion which may be acting as contributing factors to the disease process."[11]

However, current treatment planning strategies for patients with missing teeth and secondary dentoalveolar collapse (DAC) frequently neglect to incorporate important occlusal improvements and orthodontic biomechanical components of orthodontics to the treatment plan. Bone remodeling advantages made possible by tooth movement are often bypassed. For example, in Misch's recently published 1088-page textbook on implant dentistry, there are only 2 pages that discuss the value of orthodontics in cases of DAC, and these pages discussed orthodontics only as an aid for implant site development *(accelerated eruption before extraction and implant replacement)*.[92]

Many dental providers encourage expedited treatment plans for patients with missing teeth, and as a result, key orthodontic considerations have been undervalued and therefore generate minimal attention to those providing expertise on implants and their restoration. The key considerations that are often overlooked in oral rehabilitation procedures are:

1. Updated understanding of principles of bone physiology (originally Wolff's law) particularly as it relates to the alveolar bone:

   "There are no mathematical optimization rules for bone architecture; there is just a biological regulatory process, producing a structure adapted to mechanical demands by the nature of its characteristics, adequate for evolutionary endurance."[14] In this regard, Atwood documented the degree of bone loss that can occur, over time with tooth loss in the anterior segment of the mandible (Figure 24-22).
2. Epigenetic components of alveolar development and maintenance (functional matrix hypothesis (FMH) of Moss):

   "More precisely, the FMH claims that epigenetic, extra-skeletal factors and processes are the prior, proximate, extrinsic, and primary cause of all adaptive, secondary responses of skeletal tissues and organs. It follows that the responses of the skeletal unit (bone and cartilage) cells and tissues are not directly regulated by informational content of the intrinsic skeletal cell genome per se. Rather, this additional, extrinsic, epigenetic information is created by functional matrix operations.
3. Tooth movement induced alveolar remodeling.[93,94] According to the equilibrium theory of tooth position of Weinstein with new concepts of orthodontic tooth movement must be taken into consideration over time:

> **Conclusion 1.** Forces exerted upon the crown of the tooth by the surrounding soft tissue may be sufficient to cause tooth movement in the same manner as that produced by orthodontic appliances.
>
> **Conclusion 3:** Differential forces, even when they are of small magnitude, if applied over a considerable period of time can cause important changes in tooth position (DAC).[95]

Weinstein et al.'s work in 1963 coupled with recent work of Masella and Meister bring us to a clearer understanding of the orthodontist's role as *bioengineer*.

> Adaptive biochemical response to applied orthodontic force is a highly sophisticated process. Many layers of networked reactions occur in and around periodontal ligament and alveolar bone cells that change mechanical force into molecular events (signal transduction) and orthodontic tooth movement (OTM). Osteoblasts and osteoclasts are sensitive environment-to-genome-to-environment communicators, capable of restoring system homeostasis disturbed by orthodontic mechanics. Five micro-environments are altered by orthodontic force: extracellular matrix, cell membrane, cytoskeleton, nuclear protein matrix, and genome. Gene activation (or suppression) is the point at which input becomes output, and further changes occur in all 5 environments. Hundreds of genes and thousands of proteins participate in OTM.[96]

Because dentists frequently refer patients with missing teeth to the orthodontist for treatment planning, the orthodontist becomes the "gatekeeper" in the following:

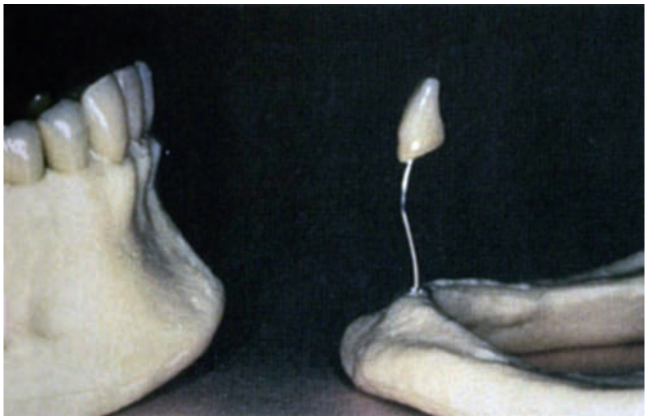

FIGURE 24-22 Alveolar bone requires the function of the dentition to avoid progressive atrophy. This vivid photograph illustrates how much alveolar bone can be lost over time when there is no dentition and no function. Preserving the dentition and the alveolar process are key responsibilities of general dentists and orthodontists.

1. Determining whether the collapse will be reversed or camouflaged (Figure 24-23, Boxes 24-2 and 24-3)
2. Setting up the spacing for tooth/root replacement
3. Aiding in the provision of temporary tooth replacement

BOX 24-2 **Characteristics of Dentoalveolar Collapse**

- Missing tooth/teeth
- Migration of adjacent teeth into area of missing tooth/teeth
- Migration of adjacent teeth is in horizontal, transverse, and/or vertical plane
- Time impacts degree of tooth migration
- Alveolar changes (atrophy) related to the missing teeth are progressive until new equilibrium positions are achieved with accompanying bone loading

BOX 24-3 **Etiology of Dentoalveolar Collapse**

Collapse secondary to:

- Early loss of deciduous teeth (especially c's and e's—this may not be addressed until adult treatment)
- Delayed exfoliation of deciduous molars
- Ankylosis of deciduous molars
- Missing first molars
- Missing second premolars
- Missing upper anteriors (congenital absence or trauma)
- Missing lower anteriors (congenital absence or trauma)
- Unilateral or bilateral cleft repair
- Cancer and bone resections

Application of Principles

Understanding the physiologic principles of alveolar bone remodeling and the role that tooth movement can play in guiding bone preservation and regeneration can alter the choices made when patients proceed through the treatment-planning process. Prevention of alveolar collapse (AC) through alveolar bone preservation and reversal of AC through alveolar bone regeneration apply to patients in the deciduous dentition, mixed dentition, and adult dentition. Often the orthodontist is the key person in the treatment plan for patients with missing teeth and should consider the implications of AC when developing the treatment plan.

The following cases illustrate the application of the principles of alveolar preservation and collapse reversal for varying age groups. Figures 24-24 through 24-26 demonstrate how components of DAC impact the many aspects of the malocclusion and frequently require a treatment plan to include implants and restoration to stabilize DAC reversal.

Conclusion for AIT Patients with Missing Teeth and Dentoalveolar Collapse

Patients with a diagnosis of AC due to tooth loss or congenital absence should be notified of the etiology of this aspect of their malocclusion and guided to the most predictable methods of successful oral rehabilitation. Dental teams will benefit from bringing each specialty's unique perspective into treatment planning for patients who present with characteristics of DAC. Most DAC cases require:

1. Etiologic recognition
2. Early collapse reversal through orthodontic measures
3. Alveolar bone stabilization through implant placement when facial growth is complete
4. Followed shortly thereafter with occlusal stabilization through restoration

Although this seems to be a simple concept to understand and to apply, the range of situations that are part of the AC "umbrella" of conditions has, to this point, been undocumented in the orthodontic literature. As recent as 1996 a survey published in the *Journal of Clinical Orthodontics* presented their findings related to three conditions that frequently occur when there is AC:

1. "When questioned about their preferred approach to manage patients with congenitally missing maxillary laterals, *nearly 80%* of orthodontists preferred substitution of canines for the missing laterals."[74] Current studies indicate a 2.2% incidence of missing lateral incisors.[97]
2. When questioned about their preference for congenitally missing lower second premolars, the majority chose forward movement of molars.[74] Current studies indicate a 3.4% incidence of second premolar agenesis with lack of a single premolar being most

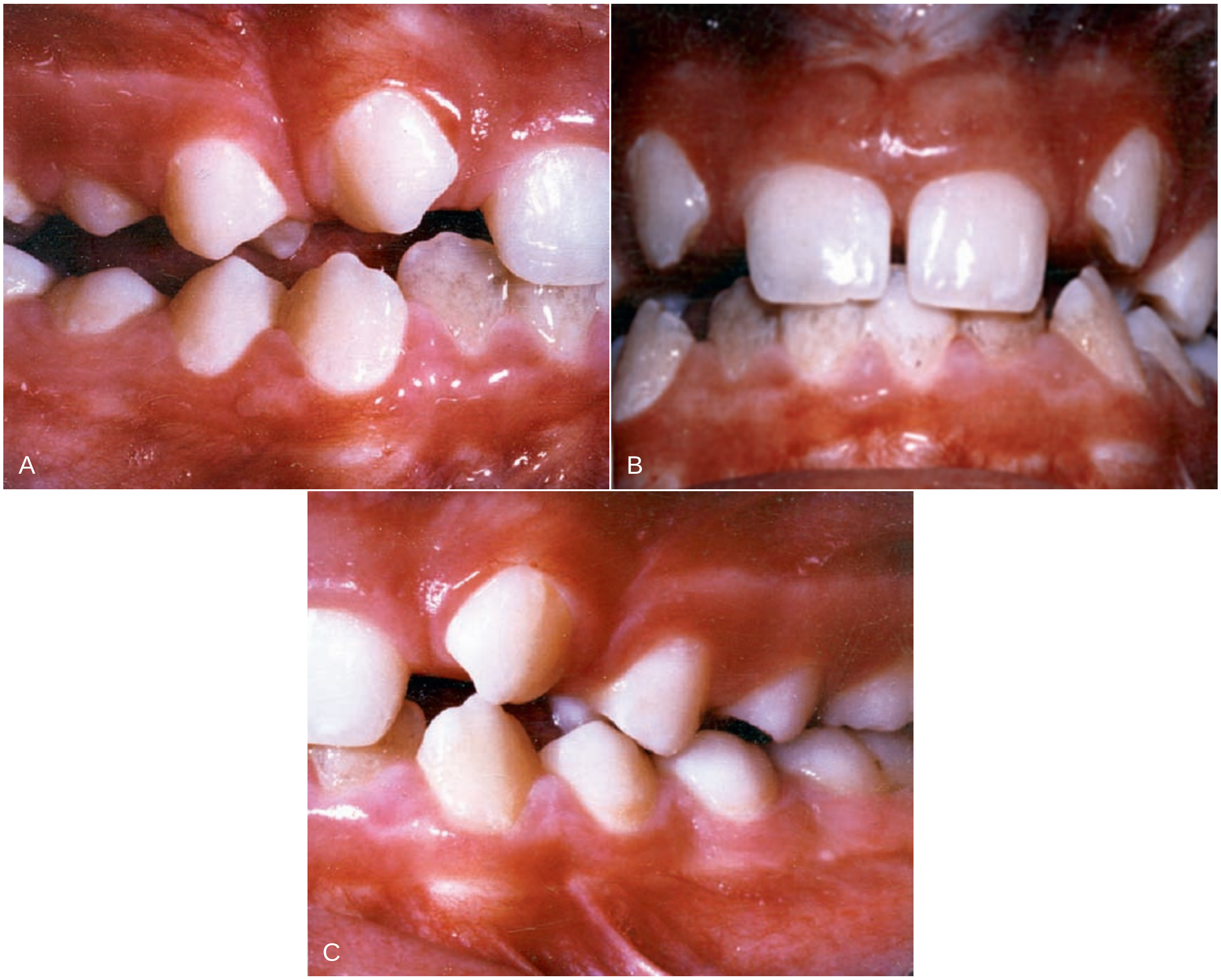

FIGURE 24-23 In patients with congenitally missing teeth, orthodontists frequently have to decide whether the "collapse" into the area of congenital absence should be reversed and stabilized with implants or camouflaged with substitution of adjacent teeth. **A–C,** Pretreatment intraoral photographs of a 14-year-old female who has congenital absence of #7 and #10. **D–F,** Posttreatment intraoral photographs of 16.5-year-old female above in which decision was made to "reverse" the anterior arch collapse and to move canines into their correct anatomical and functional position. **G,** Pretreatment smile showing unaesthetic spacing in the areas of the missing lateral incisors. **H,** Posttreatment smile illustrating dental, occlusal, and alveolar stabilization following implant replacement with crowns for teeth #7 and #10. Favorable aesthetic balance was achieved with the decision to reverse the dentoalveolar collapse. **I,** Posttreatment panoramic radiograph illustrating properly positioned implants allowing long-term health and function.

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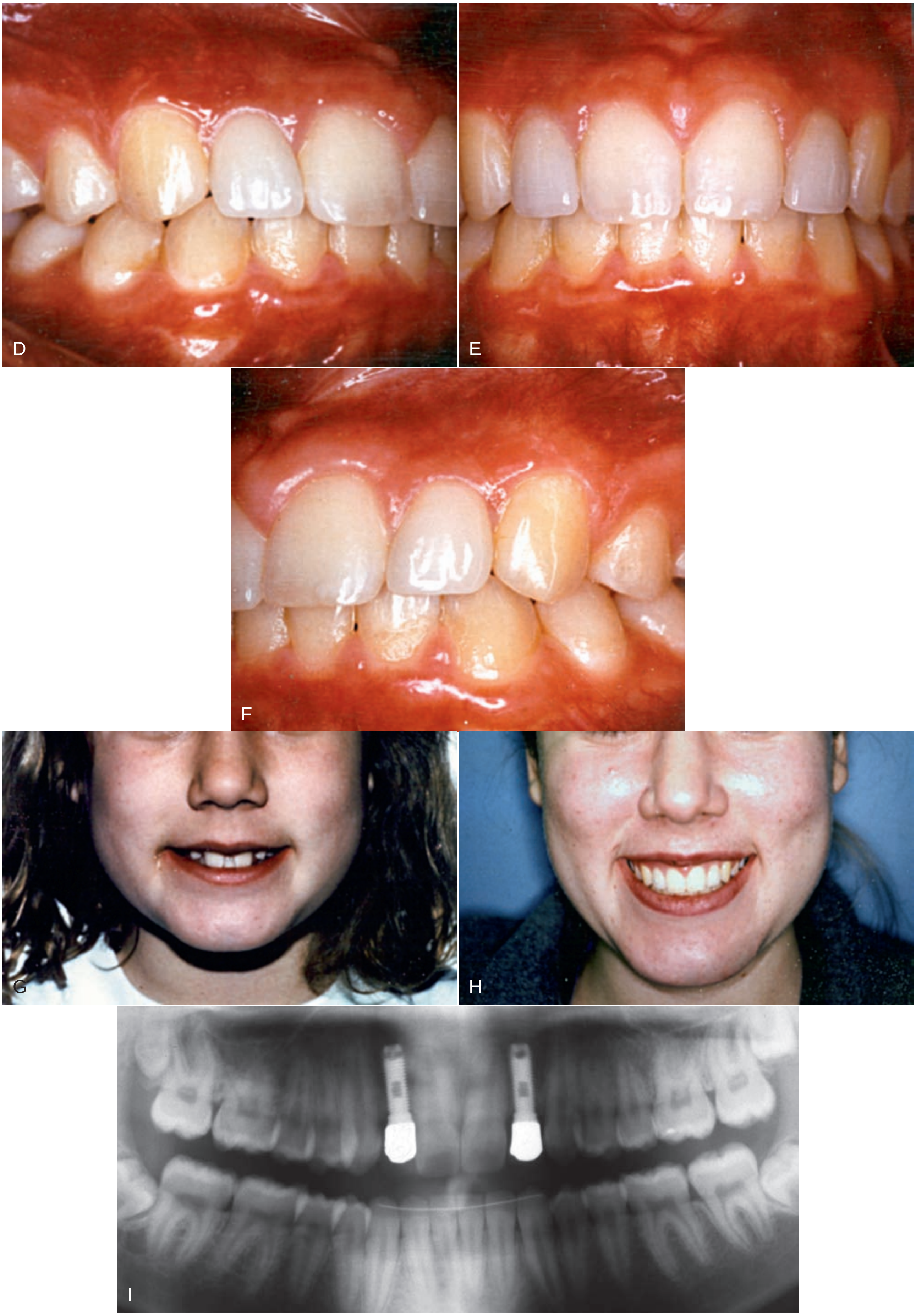
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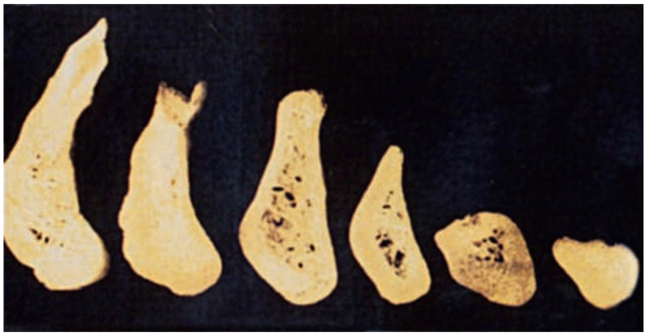

FIGURE 24-24 Atwood's work illustrates the significant alveolar atrophy that accompanies the absence of teeth and roots in the anterior portion of the mandible. This documentation should be a constant reminder of the responsibility of all members of the dental profession to preserve the natural dentition or replace teeth that are lost with implants as soon as is possible.

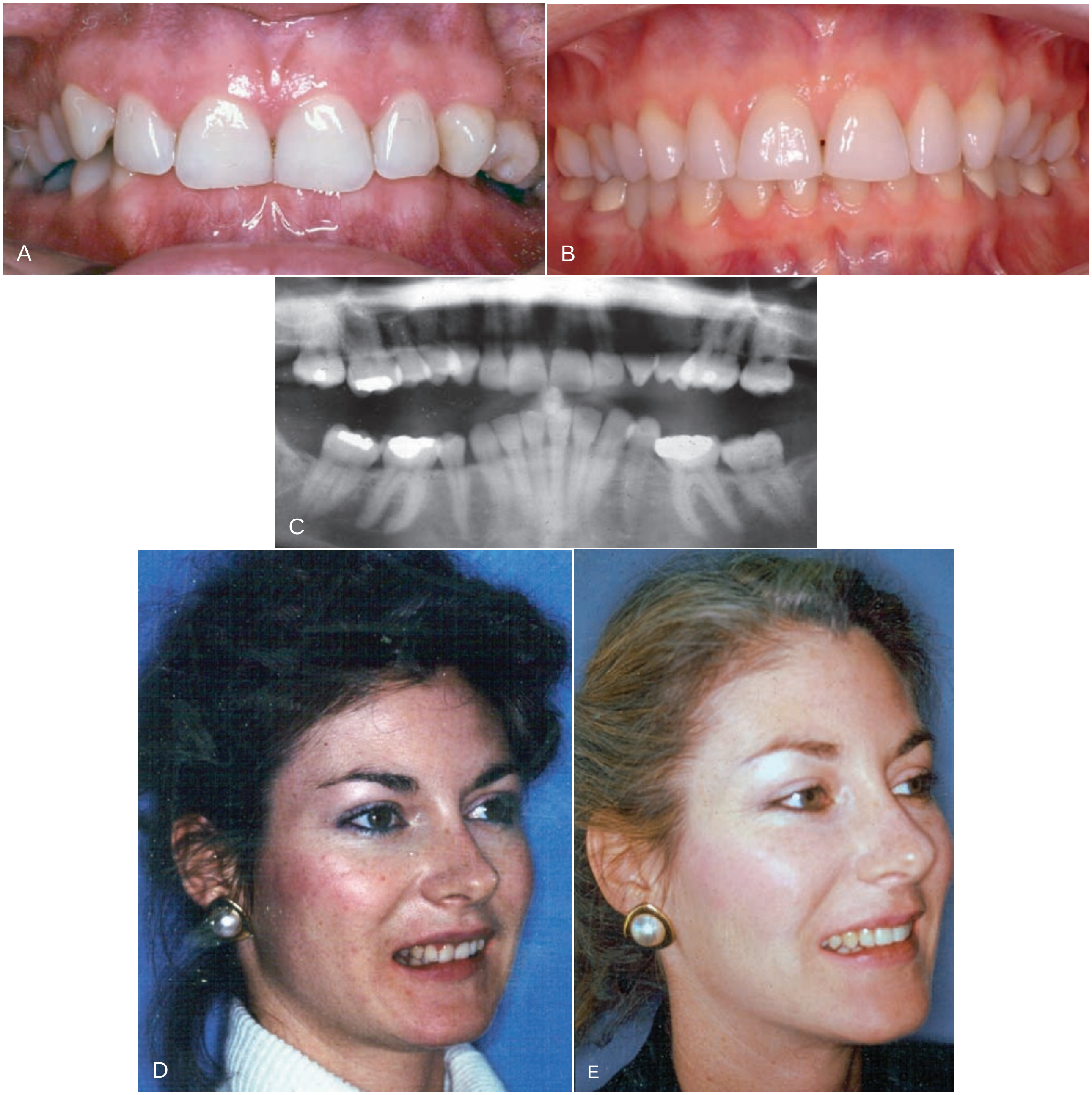

FIGURE 24-25 **A,** Pretreatment photo of the anterior dentition of a young adult who had congenital absence of #20, #29, and #13. The missing posterior teeth and the subsequent extraction of deciduous "K and T" resulted in progressive dentoalveolar collapse of the posterior and anterior portion of her dentition. **B,** Posttreatment of the anterior dentition after two years of orthodontic treatment to reverse the posterior and anterior collapse and open the space for the missing lower second premolars. Current dental therapy would use implants to replace the missing premolars; 20 years ago the collapse reversal was stabilized with bridges on the right and left posterior. **C,** Pretreatment panoramic radiograph showing the missing premolars—#13, #20, #29. Overeruption of the upper and lower incisors can be seen as well. **D,** Pretreatment ¾ posed smile photograph illustration of the retroinclination of the incisors secondary to the progressive dentoalveolar collapse and overeruption. **E,** Posttreatment ¾ posed smile photograph illustrating improved aesthetics of reangled incisors as the arch collapse was reversed and the interincisal angle improved.

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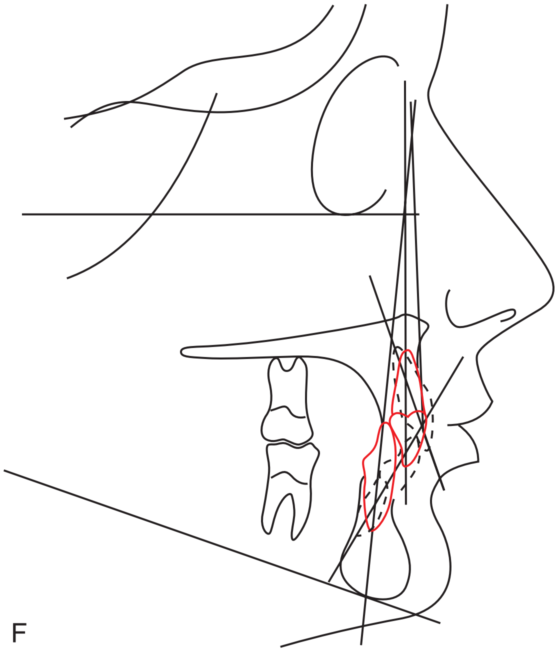

FIGURE 24-25, cont'd **F,** Cephalometric supraimposition illustrating the improved interincisal angle. Pretreatment interincisal angle was 176 degrees and posttreatment interincisal angle was 137 degrees.

frequent, and absence of three premolars occurs least frequently.[97]

3. Again, for the condition of congenital absence of a lower incisor, the majority of surveyed orthodontists preferred to accept the occlusal discrepancy and deep bite to space opening.[74]

Implant reliability and interdisciplinary interaction have improved the awareness of the orthodontists to the implant option when teeth are missing. In assessing the cases illustrated in the Applications of Principles section (see Figures 24-24 through 24-26), the concept of AC is better understood as an etiologic factor complicating the severity of many features of a malocclusion. It is the authors' opinion that as the short- and long-term impacts of DAC on the occlusion and the alveolar bone become better understood, dentistry will be better able to provide optimal care by achieving the goals of occlusal stability, dental and facial aesthetics, and bone preservation.

The issues related to sequencing treatment for patients with skeletal problems, susceptibility to periodontal disease, TMDs, and DAC with restorative requirements add to the list of intraprovider planning requirements. Clearly, improved technology, patient education, and interdisciplinary team work allow dental providers to achieve outstanding outcomes and achieve treatment goals of function, aesthetics, stability, and health through the use of reliable methods that thereby reestablish longevity to the "mutilated" stomatognathic system.

Evaluation before Debonding or Debanding

The orthodontist should consider the following before debonding or debanding:

1. **Root parallelism:** The orthodontist must verify this by panoramic, periapical radiographs or a cone-beam scan (for select situations.) This assessment can be done during progress records about three fourths of the way through treatment.
2. **Coincidence of centric relation and habitual occlusion:** This can be done through clinical assessment with the aid of deprogramming appliances.
3. **Incisal guidance:** The orthodontist should evaluate this clinically, in some cases, with mounted study models.
4. **Joint symptoms:** These should be assessed clinically and appropriate treatment or referral provided as needed.
5. **Excursive movements:** The orthodontist examines these clinically and augments examination in some cases with mounted models.
6. **Patient input:** The orthodontist should encourage patients to discuss existing dentofacial aesthetics before appliance removal. Many patients point out concerns that may be correctable with minor modifications in mechanotherapy.
7. **Reaffirmation of restorative commitment:** The orthodontist should review this commitment with the patient and discuss it with the restorative dentist and the periodontist. The timing of the restorative procedures and the coordination of restorative treatment with the orthodontic retention schedule are very important.
8. **Reevaluation of periodontal considerations:** The orthodontist reevaluates clinically with radiographs; the orthodontist should also check for mobility and fremitus, perform probing, and make a careful gingival tissue assessment.
9. **Reevaluation of anterior and posterior tooth size discrepancies:** The orthodontist informs the patient

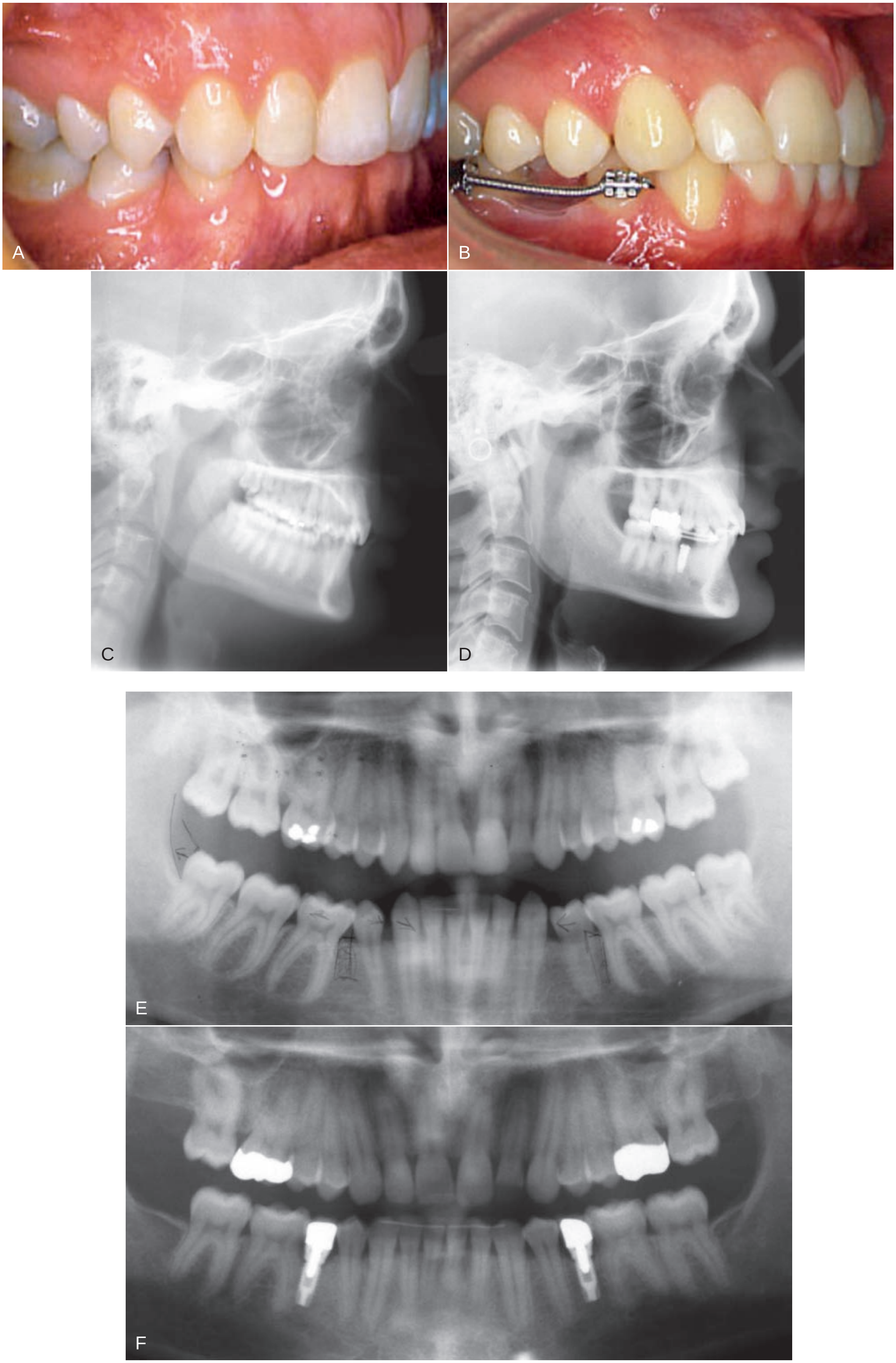
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FIGURE 24-26 **A,** Pretreatment side view of right posterior occlusion showing Class II canine relationship, but with a Class I molar relationship. The upper incisors are very upright and the bite is very deep with apparent lack of second premolar. **B,** Postorthodontic side view of the right posterior occlusion after orthodontics to reverse the dentoalveolar collapse, reangle the incisors, "open the bite," and prepare for posterior restoration to stabilize anterior and posterior occlusion. **C,** Pretreatment view of lateral cephalogram illustrating the "collapsed" dentoalveolar relationship with very upright incisors with minimal vertical "stops." **D,** Postorthodontic interincisal relationship corrected with a normal interincisal angle, which will provide long-term vertical stability in the area of the incisors. **E,** Pretreatment panoramic radiograph showing the congenital absence of the lower second premolars. The third molars are present and some of the third molars are only partially erupted. The third molars require removal to allow collapse reversal and occlusal correction with space reopening in areas of #20 and #29. This will also allow proper replacement of the missing second premolars. **F,** Posttreatment panoramic radiograph showing the space opened at #20 and #29 with implants placed to preserve the alveolar housing and crowns placed to preserve the corrected occlusion.

and the general dentist of additional measure that may be necessary to resolve tooth size discrepancies without adversely altering the posterior occlusal relationships or incisal guidance (i.e., acid-etched *add-on* technique).

10. **Anticipated retention problems**: The orthodontist should make plans and provisions and should enter them on the patient's chart if retention problems are anticipated so that problem-solving steps can be recalled easily in the future as indicated.
11. **Reassessment of the characteristics of the original malocclusion:** This is helpful to determine the specific anatomic retention needs of the case (i.e., skeletal or dental deep bite situations, openbite, or overcorrection of rotations) (Figure 24-27).

Coordination of Debonding or Debanding with Other Treatment Providers

The orthodontist should also consider the following to coordinate debonding and debanding with other treatment providers:

1. Posttreatment radiographs
2. Periodontal reevaluation and treatment
3. Restorative treatment and retention considerations: frequently, this may include the use of stabilizing sectional appliances that can be removed by the restorative dentist before placement of restorations. Removable appliances may be used for temporary tooth replacements when the patient is missing anterior teeth and there is an aesthetic concern.
4. Duration of the retention period: the retention period will vary according to the case type, overall restorative treatment plan, orthodontic result, and various causative factors (which again must be customized to the individual patient). Generally, the retention period for adults is longer. The weaning period from removable retainers also takes place over a longer time. To enhance the overall stability of treatment, selective grinding for centric and anterior disclusion during excursive movements is essential. In the case of significant (2.5 mm or more) centric relation to centric occlusion discrepancy, occlusal adjustment is required. A Hawley appliance with an anterior bite plane helps eliminate muscle dysfunction and facilitates selective grinding to achieve a stable centric relation position.

STABILITY AND RETENTION INDIVIDUALIZED FOR THE INTERDISCIPLINARY ADULT THERAPY PATIENT

Treating a Class I relationship in teenage patients in which the skeletal bases are normal is usually satisfactory and often quite stable. Unfortunately, these are not the clinical circumstances presented by most adult patients. Frequently, adults have skeletal Class II problems that are more appropriately treated with extraction in the upper arch only; the outcome is finished with a Class II molar relationship that usually requires occlusal adjustment by selective grinding that may or may not be done. A tooth size discrepancy is created by removing maxillary first premolars only, and this approach has been shown to be less stable than extraction in both arches. Also, the effects of the periodontium in creating instability in posttreatment orthodontic cases are well documented.[2] Picton and Moss have shown that the effects of transseptal fibers on the teeth with a constant and mesial migration of the dentition throughout life could cause incisor irregularities and crowding[98] (see Figure 24-27). Hixon and Horowitz stated in their 1969 article that "the significant point is that orthodontic therapy may temporarily alter the course of continuous physiological changes and possibly for a time can even reverse them. However, following mechanotherapy and a period of retention restraint, the developmental maturation process resumes."[98]

In addition, there has been the apical base school through the history of orthodontics (discussed in Chapter 23). Holdaway cautioned that facial harmony could be achieved as long as the apical base did not exceed a range

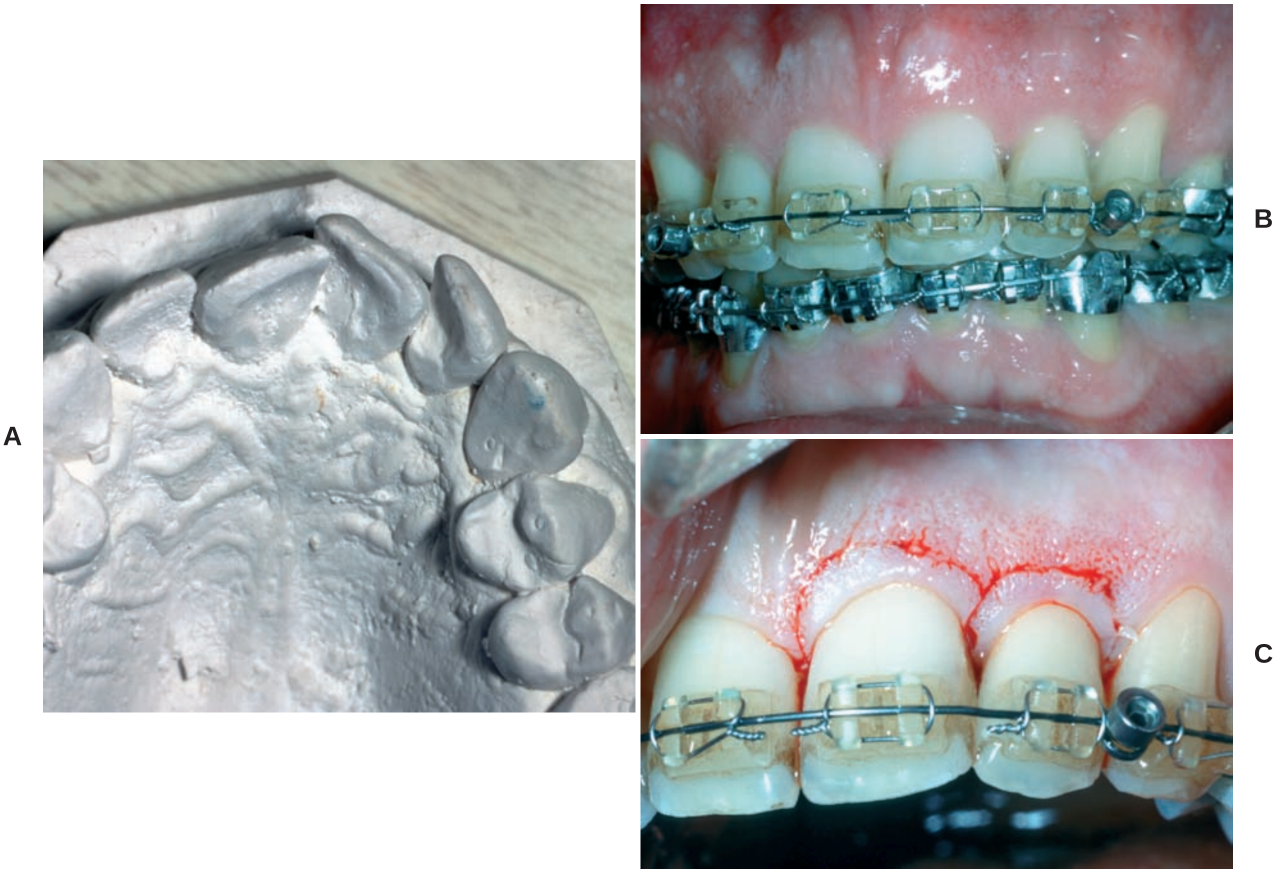


FIGURE 24-27 **A,** Before maxillary left central and lateral incisor rotations. **B,** Incisors correctly aligned. **C,** Before appliance removal; a circumferential fiberotomy was performed to enhance posttreatment stability.

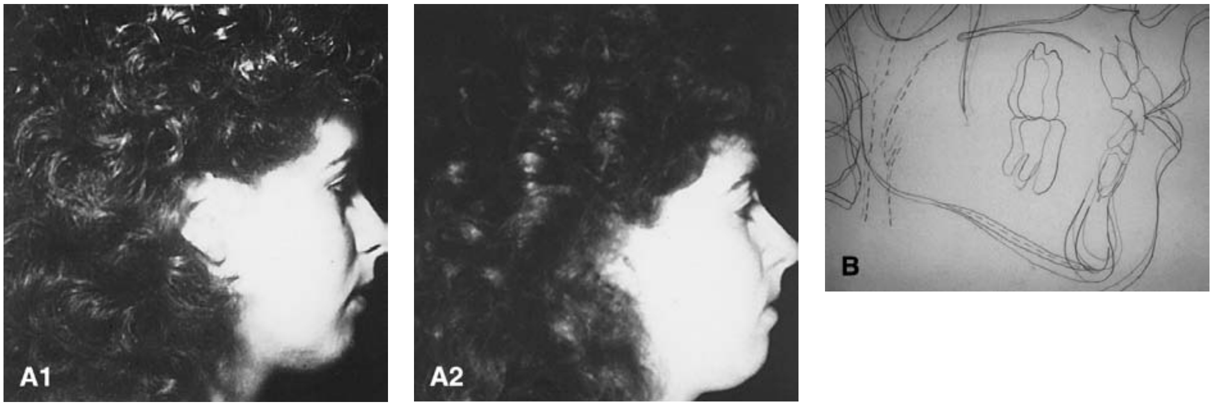


FIGURE 24-28 **A,** Pretreatment and posttreatment facial profile photographs indicate little change with removal of four premolars. **B,** Cephalometric superimposition illustrates upper incisor retraction to obtain incisal guidance.

permitting compensating dental adjustments.[99] Apical base discrepancies are tremendously limiting factors in adult treatment.

As illustrated in Figure 24-28, a Class II female adult patient underwent the extraction of upper and lower first premolars because of mild crowding, but had a sagittal skeletal discrepancy of 8 degrees and a rather normal vertical pattern (an FMA of 22 degrees); note that more dental compensation was placed in the upper incisors than in the lower incisors. Also observe the unaesthetic dentofacial change. In addition, the patient experienced significant loss of attachment, root resorption (over a 2- or 3-year period), and generalized spacing as the result of an inability to close extraction spaces in this severe sagittal discrepancy. Figure 24-29 demonstrates the skeletal limitations of orthodontic treatment, particularly in

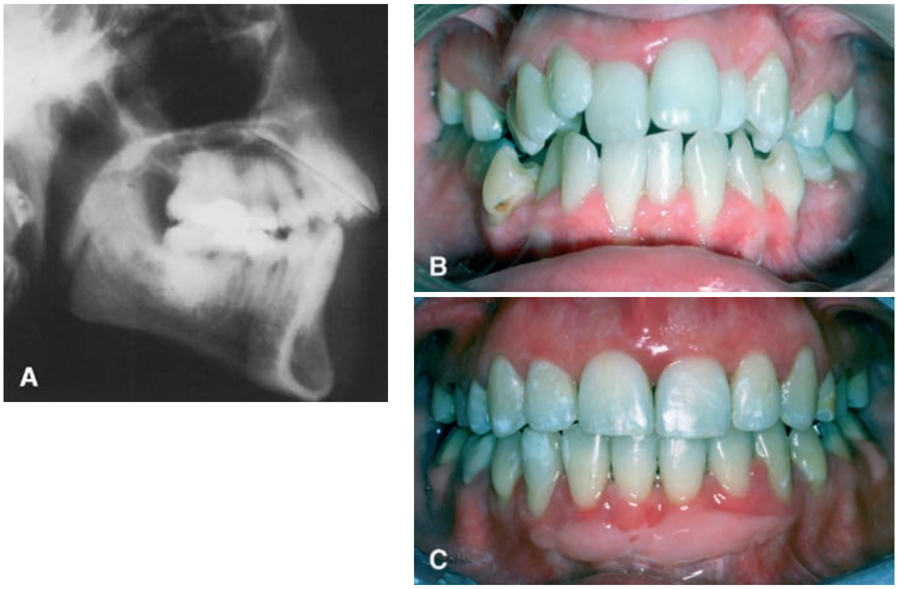


FIGURE 24-29 **A,** Pretreatment cephalometric film reveals an anterior open bite and overjet. **B,** Pretreatment alignment. **C,** Posttreatment alignment.

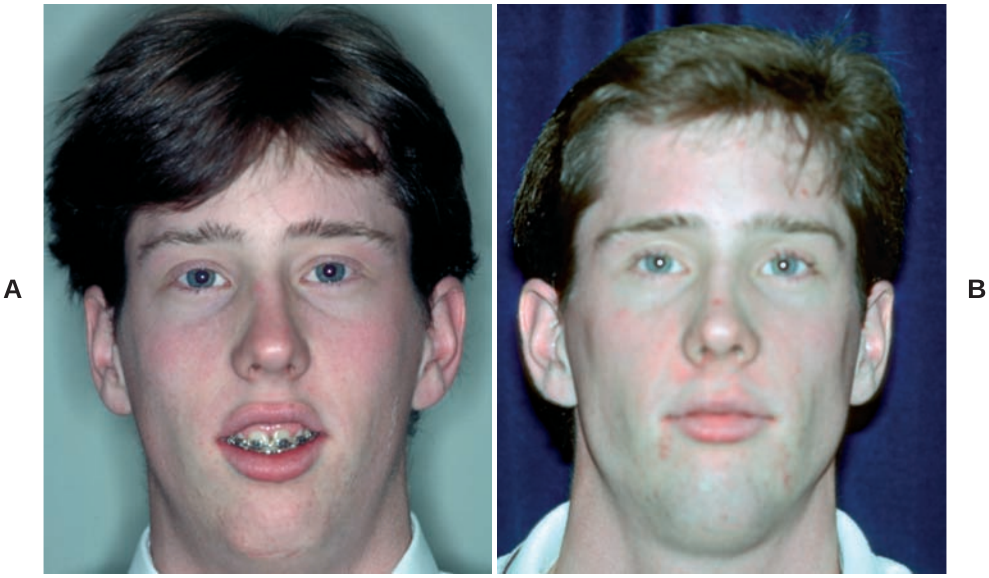


FIGURE 24-30 **A,** Long-faced patient who initially refused surgery and after 1.5 years of orthodontics requested to be reevaluated for a maxillary impaction. **B,** Appearance after orthognathic surgery. Note the excellent lip competency.

adult patients. The sagittal limitations, without camouflaging the skeletal discrepancy, with a normal vertical relationship would be approximately a Class II ANB of 7 or 8 degrees (this would exclude bimaxillary protrusion), and in the Class III skeletal problems, an ANB of –3 degrees usually requires restorative procedures or orthognathic surgery to achieve compensated anterior tooth stability. With patterns that involve vertical openbite, excessive face height, and associated muscle problems, it is common with the use of vertical elastics to encounter more root-blunting resorption. Clinicians are well aware of the problems of Class II elastics in high-angle cases, tending to tip the occlusal plane, moving the lower dentition forward, and creating periodontal problems that result in discrepancies in centric relation and habitual occlusion.

The familiar long face problem exhibits excessive eruption of maxillary teeth, maxillary transverse constrictions, excessive overjet, anterior openbite, and associated mouth breathing. This patient, with a long face and a gingival smile, who elected to go through orthodontic treatment first, could only have been improved to look as he does on the right through the use of the Le Fort osteotomy technique (Figure 24-30).

In adult treatment, common pitfalls leading to instability are as follows:

1. Tendency to extract premolars in borderline cases, and extracting in the lower arch as well, when the mandibular dentition is more distally placed
2. With vertical excess problems of lip incompetency, extracting upper premolars only
3. Attempting to close excessive extraction spaces when the problem should be treatment planned for alignment of the teeth, and using prosthetic replacements to replace teeth rather than attempting space closure

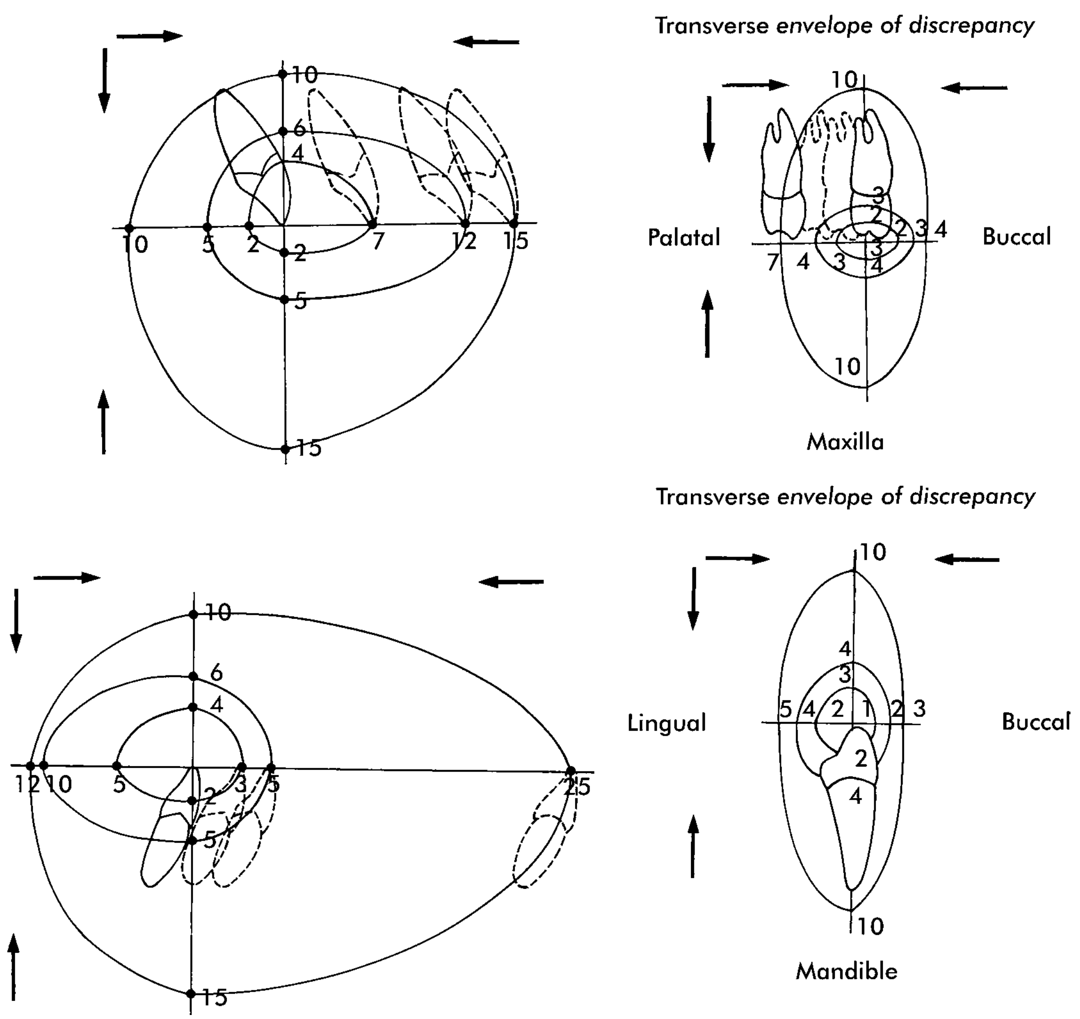
A significant report was made by Casko and Shepherd[100] in the *Angle Orthodontist* in 1984; the authors evaluated 79 untreated adults with ideal Class I dental occlusions. None of the patients subjectively were thought to have poor or unacceptable profiles. Casko and Shepherd discovered that the cephalometric values for the skeletal discrepancies in this group were far beyond mean figures often used as treatment goals. Figure 24-31 illustrates the envelope of discrepancy in the sagittal and vertical dimensions and can be used as a guide when treatment planning adult patients. As well, cases must be evaluated in the transverse dimension for transverse skeletal discrepancy, also seen in Figure 24-31; this can best be done at the present time with the use of the posteroanterior (PA) radiograph. A significant skeletal discrepancy in a transverse dimension diagnosed by looking only at the dentition and attempting to use archwires to laterally expand the teeth on a constricted maxillary apical base frequently creates buccal gingival recession as one of the side effects of camouflaging patients with transverse dysplasias. Clinicians must develop an envelope of discrepancy concept for the transverse dimension, as well as for the sagittal and vertical dimension (Figure 24-31). In transverse skeletal problems for the adult, treatment options are to leave the patient in crossbite, use restorative dentistry to change the contour of the posterior teeth to achieve a more normal dental buccolingual landmark relationship, or correct the skeletal pattern by surgically assisted palatal expansion. Camouflaging the transverse skeletal deficiency by only moving the teeth may cause periodontal problems, mainly buccal gingival recession and instability of the occlusal scheme. The effective surgical procedure to use was reported in August 1976.[101]

In the transverse dimension, the clinician may elect to camouflage the skeletal discrepancy by tipping the teeth and creating occlusal instability and periodontal problems; should the surgical procedure be used, the expansion appliance should have acrylic that covers the palate. With an effective surgical procedure, tissue-borne appliances do not create excessive pressure on the palatal mucosa and will not create vascular ischemia by pressure against the palatal tissue. Tooth-borne appliances alone, however, tend to allow for more dental tipping than is seen with appliances that have acrylic on the palate. Therefore, *Hyrax-type* appliances are not recommended. The case in Figure 24-32 illustrates significant dental tipping that occurred as a result of using that appliance. A more effective appliance is the *Haas-type* appliance. The surgical procedure involves raising the mucoperiosteal tissue in the buccal vestibule bilaterally in the maxilla; a horizontal osteotomy is made through the lateral wall of the maxilla 4 to 5 mm, superior to the posterior teeth. In addition, to facilitate the separation of the maxilla, an osteotome is used between the central incisors to separate the palate. Usually the procedure is a day surgery procedure and does not require the patient to stay overnight in the hospital.

For the Class II orthodontic patient, extraction is necessary with skeletal deformities, vertical growth patterns, and bimaxillary protrusions and in the maxillary arch only. Therefore, for the Class II patient, Figures 24-28 and 24-29 show an example of limitations that exist in adult treatment. The pretreatment and posttreatment photographs (see Figure 24-28, *A*) demonstrate little change in the patient's profile, but her dental alignment is much better (see Figure 24-29, B, C). After the patient *demanded* that all appliances be removed before complete space closure, a retainer was bonded to the lower, canine to canine. The lower right molar had a large amalgam filling and was crowned so that mesiodistal contact (arch integrity) was maintained through the second molar (Figure 24-33). An operative restoration was placed on the patient's left side, and "immediate" removable retainers were inserted. An impression was taken for the upper arch with instructions for the laboratory to carve off all the brackets, and at the time the case was debonded the retainer was placed immediately because of the muscle problem (tongue thrust). The patient was given two retainers for the maxillary arch. One was worn during the day (a regular removable retainer) for an indefinite period of time until it could be left out during the day. The termination of daytime wear was indicated when the patient felt no pressure on the teeth at the insertion of the night crib appliance. The day appliance may be required for as long as a year, but the night crib is used indefinitely. The crib appliance at night prevents the tongue from being placed between the anterior teeth, which would allow for eruption of molars and a return of the open bite. The tongue appliance that is given to all patients with a forward-resting tongue posture problem is illustrated in Figure 24-34.

Patients who exhibit a tongue placement habit can also be recognized by their forward tongue placement during speech. Retention requires special consideration for posttreatment stability, as indicated in Figure 24-33.

The forward-resting tongue posture problem is significant, particularly for the adult patient who has maintained the habit of placing his or her tongue between the anterior segment beyond adolescent years. In an article



Transverse *envelope of discrepancy*

Maxilla

Transverse *envelope of discrepancy*

Mandible

FIGURE 24-31 The envelope of discrepancy for the maxillary and mandibular arches in three planes of space. The ideal position of the upper and lower incisor in the anteroposterior (AP) and vertical planes is shown in the center of the incisor diagrams. The millimeters of change required to retract a protruding incisor, move forward a posteriorly positioned incisor, or extrude or intrude an incorrectly vertically positioned incisor are shown along the horizontal and vertical axes, respectively. The limits of orthodontic tooth movement alone are represented by the inner envelope; possible changes in incisor position from combined orthopedic and orthodontic treatment in growing individuals are shown by the middle envelope; and the limits of change with combined orthodontic and surgical treatment are shown by the outer envelope.

The inner envelope for the upper arch suggests that maxillary incisors can be brought back a maximum of 7 mm by orthodontic tooth movement alone to correct protrusion but can be moved forward only 2 mm. The limit for retraction is established by the lingual cortical plate and is observed in the short term; the limit for forward movement is established by the lip and is observed in long-term stability or relapse. Upper incisors can be extruded 4 mm and depressed 2 mm, with the limits being observed in long-term stability rather than as limits on initial tooth movement.

The envelopes of discrepancy for the transverse dimension in the premolar areas are much smaller than those for incisors in the AP plane. The transverse dimension can be crucial to long-term stability, periodontal health, and frontal dentofacial aesthetics.

The orthodontic and surgical envelopes can be viewed separately for the upper and lower arches, but the growth modification envelope is the same for both: 5 mm of growth modification in the AP plane to correct Class II malocclusion is the maximum that should be anticipated, whether occlusion is achieved by acceleration of mandibular growth or restriction of maxillary growth. The outer envelope suggests that 10 mm is the limit for surgical maxillary advancement or downward movement, although the maxilla can be retracted or moved up as much as 15 mm; the mandible can be surgically set back 25 mm but can be advanced only 12 mm.

These numbers are merely guidelines and may underestimate or overestimate the possibilities for any given patient; however, they help place the potential of the three major treatment modalities in perspective.

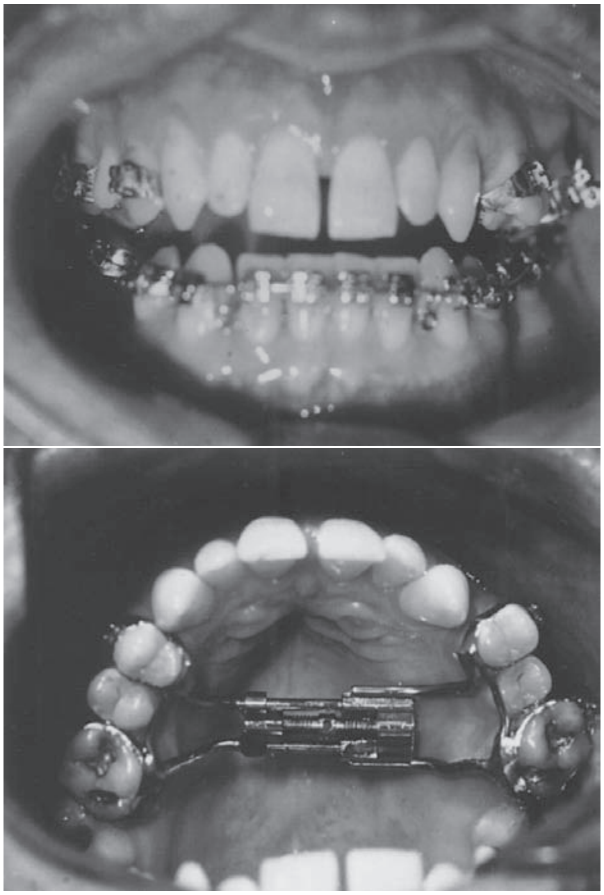


FIGURE 24-32 Frontal and occlusal view of severe dental tipping with the Hyrox-type palatal expander.

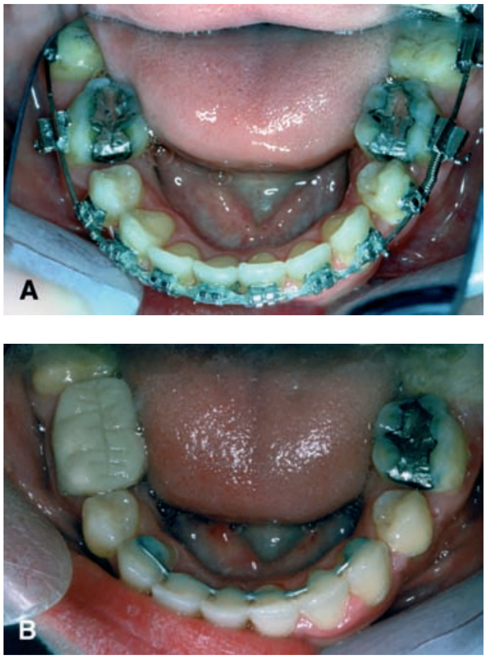


FIGURE 24-33 Same patient as in Figures 24-28 and 24-29. **A,** Note the spaces mesial and distal to the lower right molar when the patient demanded that appliances be removed. **B,** The large mandibular molar provisional was placed at the time appliances were removed.

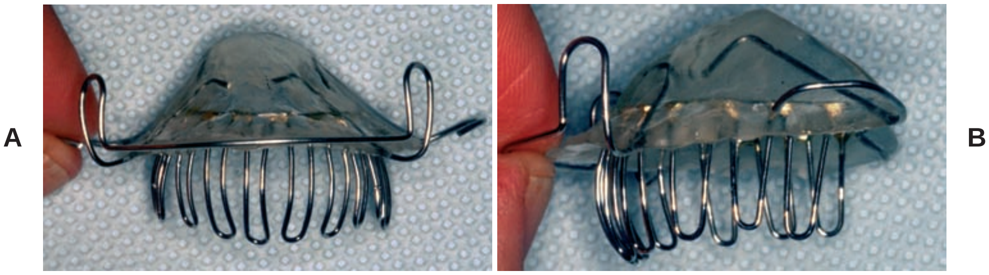


FIGURE 24-34 **A,** Anterior view of the tongue crib that is used indefinitely as a retainer. **B,** The appliance has a labial bow with ring clasps, and the crib extends back to the second molar area to the lingual mucogingival junction of the mandible when the patient is in maximal intercuspation.

published in the *Angle Orthodontist* in 1989, Denison, Kokich, and Shapiro[102] divided the sample population into three groups based on the degree of pretreatment overbite in the open bite subsample; results show clearly that the three subsamples tested responded differently during the posttreatment interval. Among the subsample, 42.9% showed a significant increase in facial height, eruption of maxillary molars, and decrease in overbite; 26.6% of the open bite sample and 16.7% of the overlap subsamples showed a significant increase in facial height, significant eruption of posterior teeth, and no change in overbite. The incisal contact sample had no significant posttreatment changes.

Among the possible reasons for posttreatment instability and one of the factors not taken into consideration in retention with this study population was the unconscious forward placement of the tongue, and a crib at night only could have prevented the open bite relapse. Open bite that recurred in 42.9% of subjects with pretreatment open bite could have been reduced with the use of a tongue crib retainer at night. As stated earlier, patients commonly place their tongue between the anterior segments, allowing vertical eruption to occur at the molars and resulting in recurrence of the dental open bite.

For skeletal Class II patients, it may be necessary to advance the lower incisors (compensation is placed in the mandibular dentition, not in the maxillary incisors) and place tooth material bilaterally in the posterior segments of the mandible, as seen in Figure 24-35, where two restorations were placed in the mandible. In Class III cases, orthodontists may compensate the maxillary incisors for the Class III skeletal pattern by adding tooth material in the maxillary posterior segments bilaterally to maintain a more procumbent maxillary incisor without allowing the upper incisors to be placed into permanent trauma or femitus because of the Class III skeletal pattern.

Figure 24-36 exhibits a Class III case in which the maxillary centrals are moved to the midline: two bridges were placed in the maxillary posterior segments, allowing the anterior teeth to be stable without putting permanent trauma on the upper anterior teeth. To remove the appliance and merely insert an upper and lower removable retainer would not ensure stability. Placing two retainers without reshaping old restorations that have been carved up in the preorthodontic occlusion

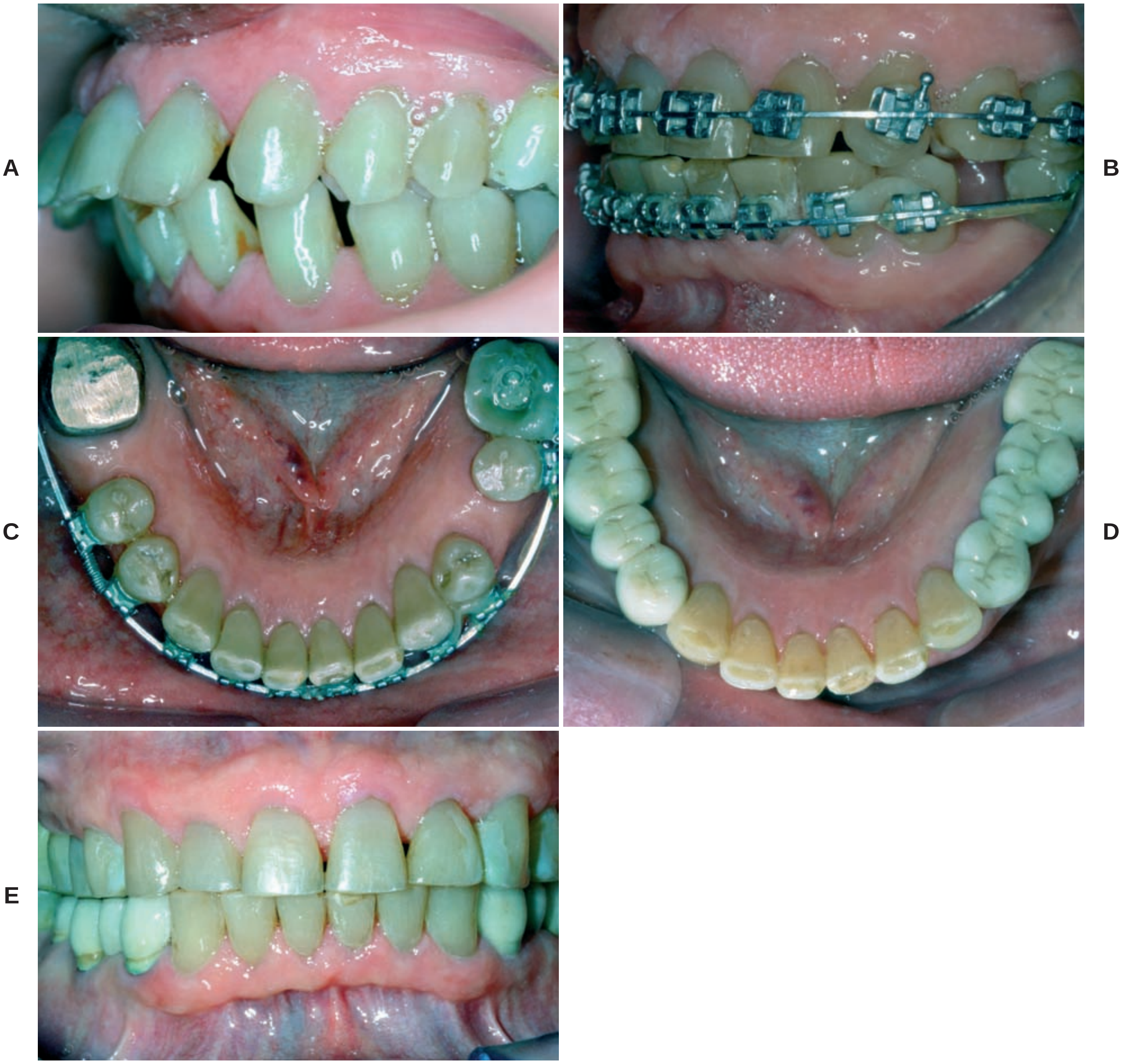


FIGURE 24-35 **A,** Left lateral view of a 59-year-old Class II adult. **B,** Lower incisors, canines, and first premolars were advanced to obtain a Class I dental relationship and incisal guidance. **C,** Mandibular arch after pontic space was created in lower left quadrant between the premolars and before a pontic space had been created between the mandibular right premolars. **D,** Postrestorative occlusal view with the bridges having been placed bilaterally, allowing the more procumbent incisors to remain stable. **E,** The compensated mandibular incisors remain stable 20 years after treatment.

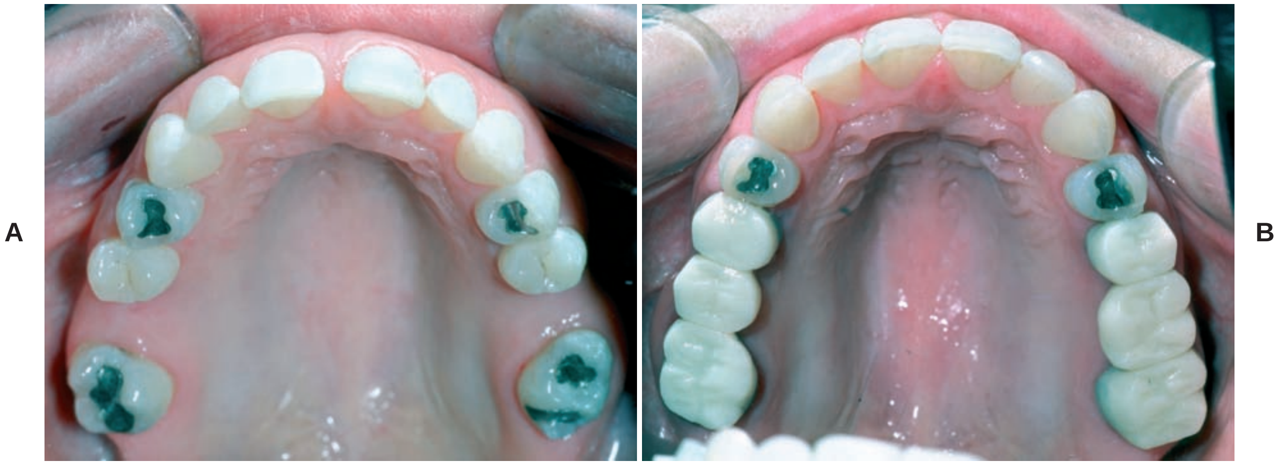


FIGURE 24-36 **A,** Occlusal view of the maxillary arch in a Class III patient who is missing posterior teeth bilaterally. If a Class III patient has an A point–nasion–B point greater than −3 degrees, space can be created bilaterally in the maxillary posterior areas and bonding material can be added mesiodistally to achieve arch integrity and maintain more procumbent maxillary incisor stability without occlusal trauma. **B,** The incisors are advanced and centered on the midline, and restorations have been placed bilaterally in posterior areas.

would not achieve stability. When tooth size discrepancies exist or when teeth are taken out, it may be necessary to reshape remaining teeth with bonding material. It is much easier to establish intimate occlusion and stability for a patient who does not have old fillings and restorations. Patients with old crowns that were carved to a previous malocclusion or large restorations and amalgams that need to be reshaped also require occlusal adjustment by selective grinding to create a definitive occlusion that coordinates maximal intercuspation and central relation.

Adaptations that occur with aging have been well described by Behrents.[103] The adult orthodontic patient will need to have indefinite retention in the mandibular anteriors. The Sillman collection at the University of Pennsylvania features long-term records of Class I individuals (who received minimal or no treatment) who had well-aligned incisors at age 13 but had crowding at 22 years of age, together with normal dentitional compensation of aging. Prerestorative space or pontic areas that are created in treatment require indefinite retention, and the forward tongue position, particularly in adults, requires a crib to be worn at night for an indefinite time.

Three important situations demand indefinite retention:

1. Patients who have generalized spacing, in which the arches are large and the tooth structure is not sufficient to close all the space
2. In circumstances of lip competency, the objective should be to transfer the space to the posterior segments and add tooth material in the posterior areas to achieve arch integrity. With adult patients the object is to keep the restorative dentistry in the posterior segments and have natural tooth material in the anterior.
3. With tooth size discrepancies in the anterior area, it may be necessary to correct the tooth material problem where the tooth size discrepancy exists. If the discrepancy is in the anterior teeth, bonding and reshaping of the anterior group are mandatory; if the discrepancy is in the posterior teeth, the solution lies in treating the posterior midline and advancing the canine and premolar teeth mesially, shifting the space to the posterior segments.

Again, it is recommended that the orthodontist refer to the basic concepts of retention outlined in Chapter 27. Those concepts and research findings can guide clinicians in further integrating a retention approach that is optimal for each patient.

Communicating with Team Members

Preorthodontic inflammation management and occlusal control can be managed by the general dentist or the periodontist, but the orthodontist should monitor this phase and evaluate patient response over time before initiating the orthodontic phase of treatment. In addition, obviously, all caries control should have been completed, overhanging margins corrected, overbulked contacts reduced, irregular marginal ridges reshaped, and endodontic procedures complete. Consequently, adult interdisciplinary dental therapy requires treatment sequencing information so that standardized communication of the treatment plan is available to the patient and all providers.

RISK MANAGEMENT AND THE ADULT INTERDISCIPLINARY THERAPY PATIENT

According to recent statistics from the AAO Council on Insurance, adult patients account for 50% of malpractice claims. Because adult patients account for less than 20% of the orthodontic patients, it would seem that each time orthodontists treat an adult versus a child, they are four times more likely to be named in some form of malpractice claim. Is the increased risk simply because the cases are more complicated? Is the increase in risk because adult patient expectations are so much higher than those of the adolescent patient and/or parent of the adolescent? Or is the problem simply a lack of communication, as several articles have suggested?[80,85]

Because almost 80% of adult patients require interdisciplinary treatment planning and treatment execution, the role of communication among providers and with the patient cannot be emphasized enough. In Roblee's text, there is an important discussion of the role of communication:

> Extensive communication between team members is crucial to the success of Interdisciplinary Therapy ... lack of communication or improper communication between team members is frequently the most common source of breakdown of therapy and of the team. The various team members must have a common purpose with the same objectives, as well as common knowledge that allows them to communicate intelligently and effectively with one another.[104]
>
> If an orthodontic clinician plans on emphasizing more availability of adult treatment to their community, they would be wise to form an interdisciplinary study group of key members of an interdisciplinary team (IDT)—periodontist, oral and maxillofacial surgeon, restorative dentist, endodontist, psychologist, physical therapist, and other professionals who might be appropriate for team interaction.

As the outline of this AIT chapter indicates, the IDT members should clarify their concepts and the team's concept of:

- Goals of treatment
- Diagnosis of AIT problems
- Sequence of treating various conditions
- Stabilization and retention

In addition, the team's approach to communicating the plan of treatment to each of the providers and to the patient needs to be very clear. Many offices that function as IDTs have assigned staff as treatment coordinators to assist in the communication process, since IDT patients frequently require occasional updates so they are kept appraised of treatment progress.

The authors suggest that a disciplined approach to patient communication be part of the treatment protocol for each patient. Four key conferences should be considered fundamental to adult interdisciplinary patient management, and with each of these conferences, it is advisable to have a written report to summarize what was said for future reference if needed.

1. Treatment Conference Report (Figure 24-37)

   The report shown is a summary of the treatment plan that was discussed and presented to the patient. It should include the diagnosis, a problem list, a plan of treatment in sequential order (including proposed future consultations), a list of providers for each procedure, as statement of the prognosis, a list of potential treatment limitations, and a statement of patient concerns. This report is frequently generated by the orthodontist member of the team.
2. Progress Report (Figure 24-38)

   After about 12 to 14 months of orthodontic treatment, photographs and a panoramic radiograph (periapicals, cephalogram, and study models are elective) should be taken and a progress report generated. This is used to evaluate tooth response, periodontal health, root positioning for restorative considerations, and potential treatment idiosyncrasies. Time should then be scheduled to provide an opportunity to sit quietly with the adult patient (other providers if indicated) to advise him or her of the progress of treatment, time remaining in treatment, and any problems or changes in the treatment plan that now need to be considered. These few minutes of the orthodontist's time are greatly appreciated by the adult interdisciplinary patient and his or her restorative dentist.
3. Stabilization/Retention Report (Figure 24-39)

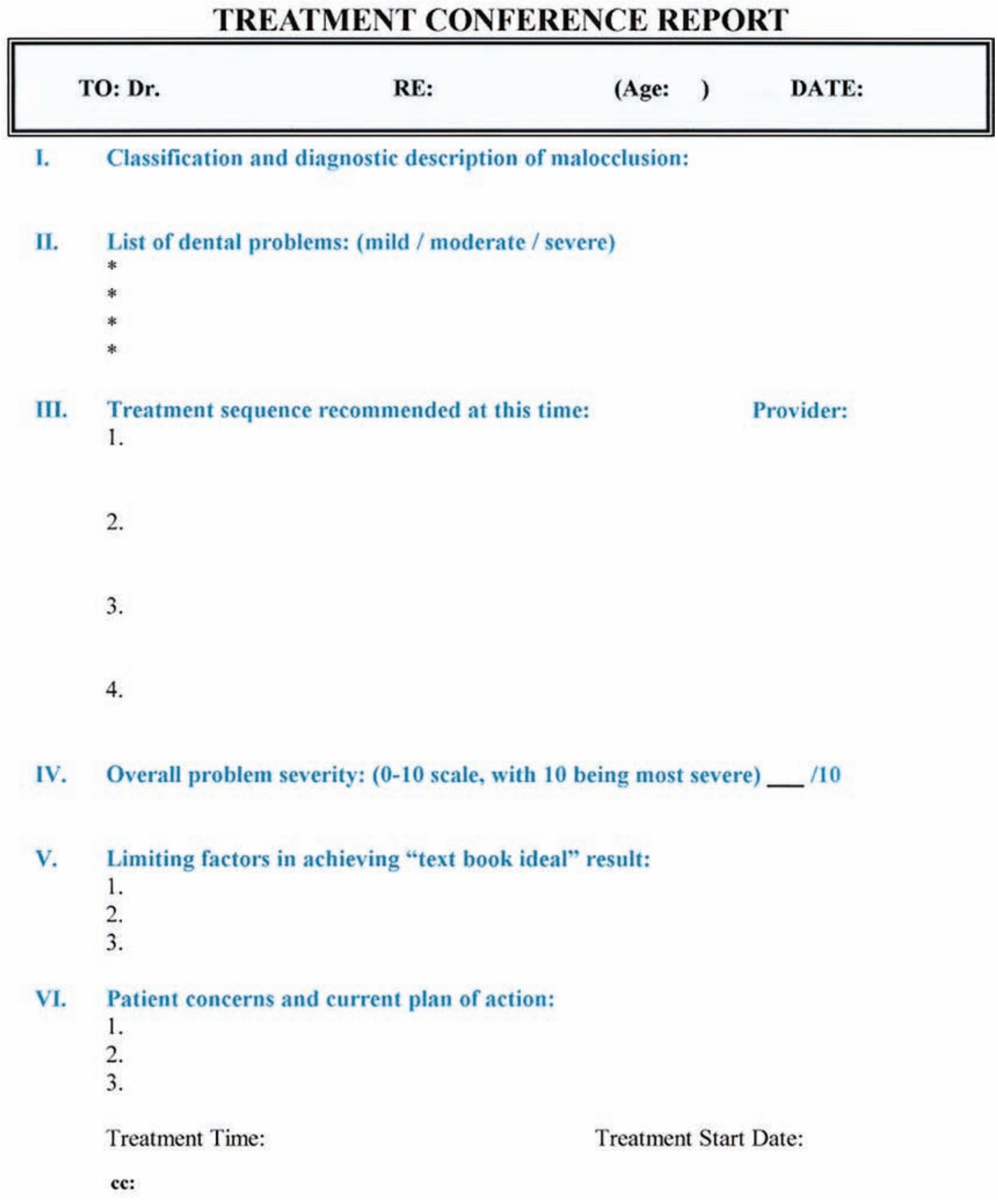
   Following removal of fixed appliances, a retention conference is scheduled and a written report is generated so that the adult patient can review the treatment and the treatment outcome. This is a great time to discuss any treatment limitations and any negative sequelae (e.g., root resorption).

   On a positive note, the authors have found that giving the adult patient a copy of before-and-after photographs is a well-appreciated good-will gesture. The photographs also illustrate to the patient the positive changes that have occurred with treatment. Also, this provides the orthodontist a good opportunity to reorient the patient to the additional periodontal and restorative procedures that are needed. Any patient concerns should be noted and appropriately managed during the retention phase of treatment.
4. Treatment Completion (Figure 24-40)

   Approximately 12 to 18 months after the removal of appliances, a final evaluation of the patient and the stability of the correction should be assessed. Again, any problems or additional treatment steps can be discussed. This is a good time for a formal review of future retention requirements that need to be considered. It is helpful to advise them of your office's availability for further retainer maintenance and what type of fees would be charged for new retainers, office visits, and bonded retainer maintenance.

SUMMARY

This chapter has described the diagnosis, planning, sequencing, and stabilizing involved in the



TREATMENT CONFERENCE REPORT

TO: Dr. RE: (Age:) DATE:

I. Classification and diagnostic description of malocclusion:

II. List of dental problems: (mild / moderate / severe)

*
*
*
*

III. Treatment sequence recommended at this time: Provider:

1.

2.

3.

4.

IV. Overall problem severity: (0-10 scale, with 10 being most severe) ___ /10

V. Limiting factors in achieving "text book ideal" result:

1.
2.
3.

VI. Patient concerns and current plan of action:

1.
2.
3.

Treatment Time: Treatment Start Date:

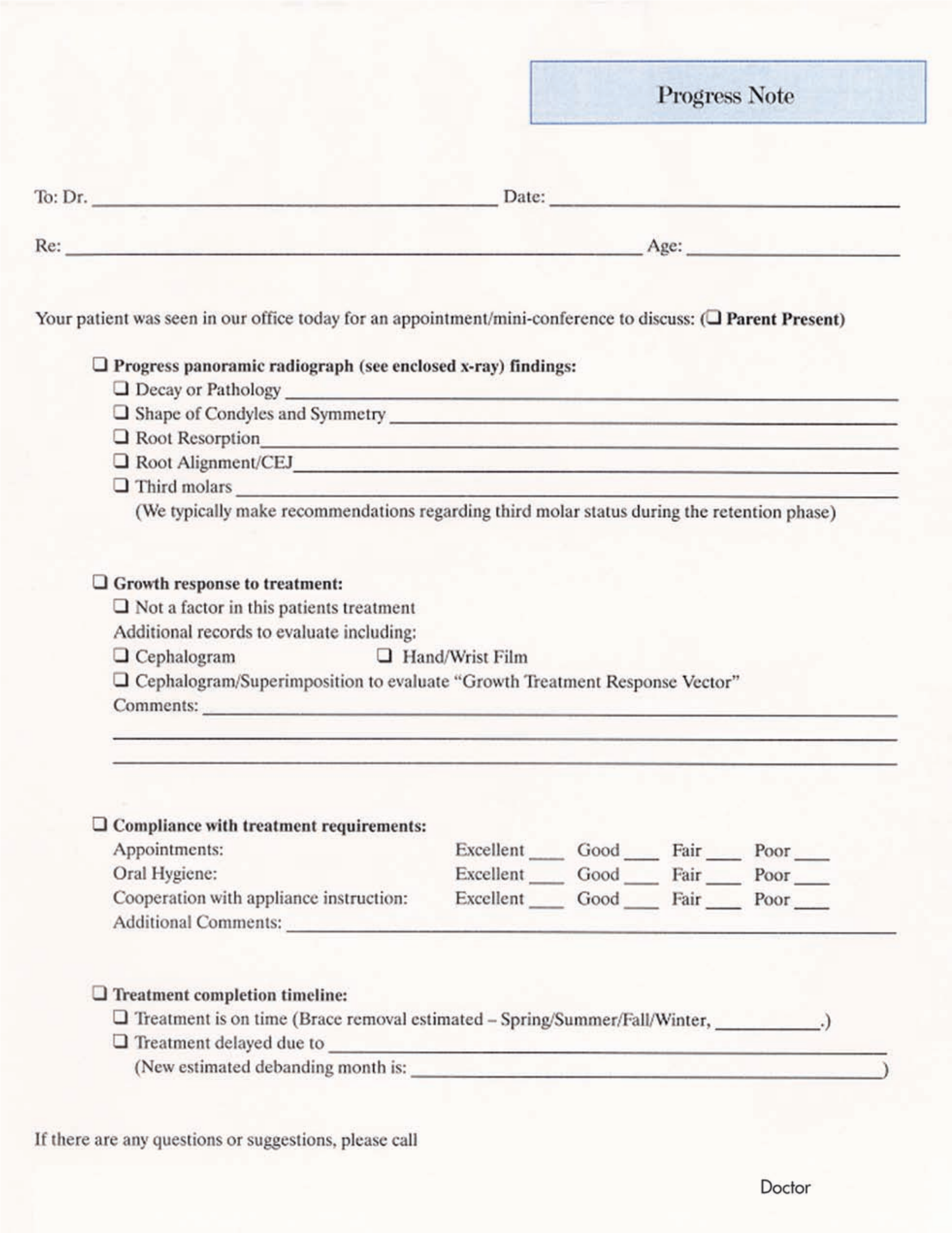
cc:

FIGURE 24-37 Sample treatment report for a patient requiring interdisciplinary therapy.

interdisciplinary management of complicated adult patient care. Advances in technology have provided IDTs with new methods of reliably managing the restoration of the stomatognathic system. In a high percentage of adult patients, interdisciplinary interaction among providers is critical. Therefore, a *disciplined* communication approach *(provided to each patient)* is required for each AIT patient. The more thorough the communication among providers and with the patient, the more likely it is that an optimal outcome will be achieved.

Acknowledgment

The authors express the deepest appreciation to the restorative dentists, periodontists, and oral and maxillofacial surgeons and their staff who make interdisciplinary therapy for our patients possible and successful. Special appreciation goes to our staff, whose diligence and professionalism has helped each patient through the intricacies of interdisciplinary dentofacial therapy. Also, special thanks to Elizabeth Barrett, Beth McFarland, Sara Ramos, and Melissa Carstens for their time and



Progress Note

To: Dr. ______________________________ Date: ____________________________

Re: ____ Age: ________________

Your patient was seen in our office today for an appointment/mini-conference to discuss: (☐ **Parent Present)**

☐ **Progress panoramic radiograph (see enclosed x-ray) findings:**
- ☐ Decay or Pathology ______________________________
- ☐ Shape of Condyles and Symmetry ______________________________
- ☐ Root Resorption ______________________________
- ☐ Root Alignment/CEJ ______________________________
- ☐ Third molars ______________________________

(We typically make recommendations regarding third molar status during the retention phase)

☐ **Growth response to treatment:**
- ☐ Not a factor in this patients treatment

Additional records to evaluate including:
- ☐ Cephalogram ☐ Hand/Wrist Film
- ☐ Cephalogram/Superimposition to evaluate "Growth Treatment Response Vector"

Comments: ______________________________

____

____

☐ **Compliance with treatment requirements:**

Appointments:	Excellent ___	Good ___	Fair ___	Poor ___
Oral Hygiene:	Excellent ___	Good ___	Fair ___	Poor ___
Cooperation with appliance instruction:	Excellent ___	Good ___	Fair ___	Poor ___

Additional Comments: ______________________________

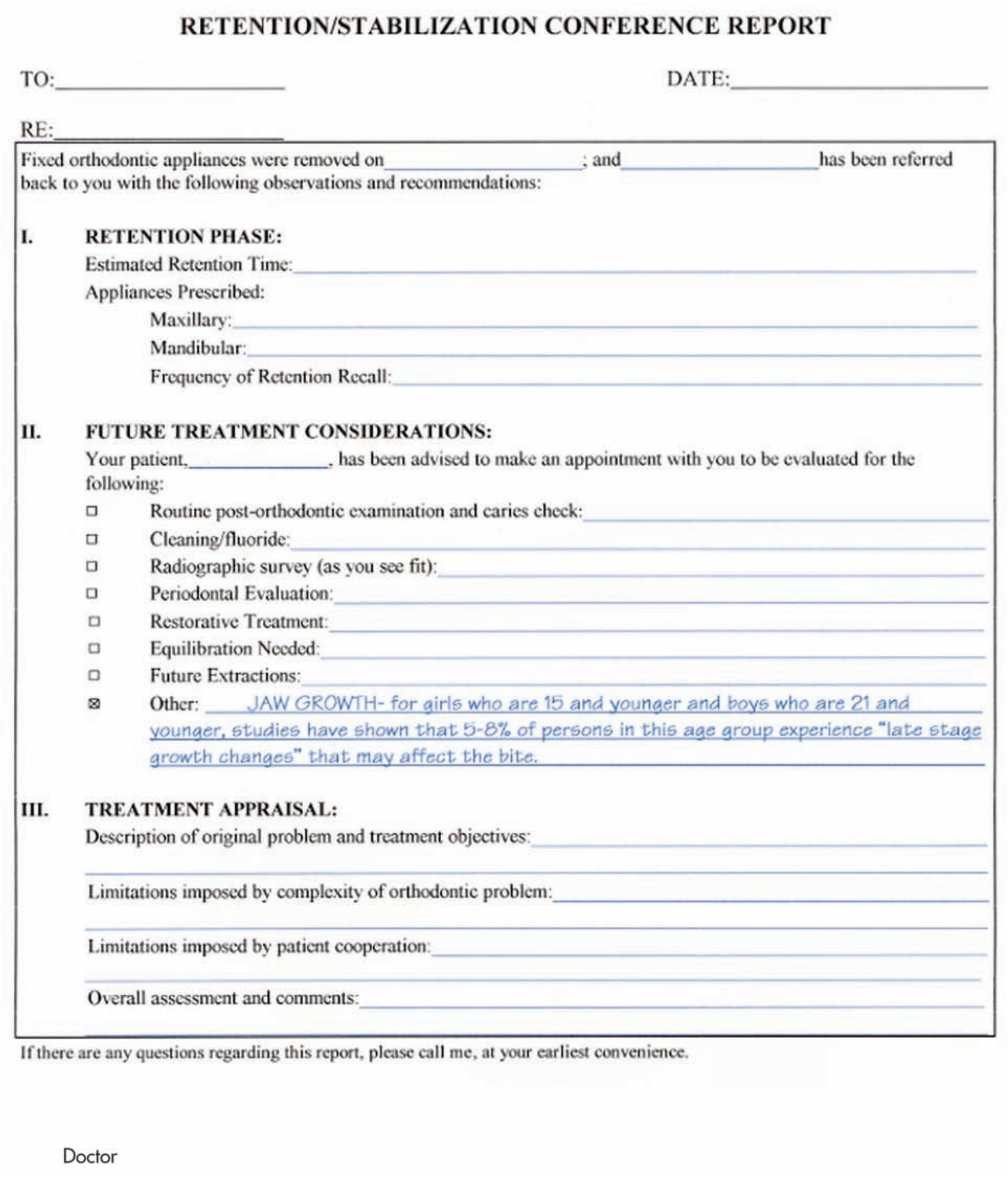
☐ **Treatment completion timeline:**
- ☐ Treatment is on time (Brace removal estimated – Spring/Summer/Fall/Winter, __________.)
- ☐ Treatment delayed due to ______________________________

(New estimated debanding month is: ______________________________)

If there are any questions or suggestions, please call

Doctor

FIGURE 24-38 Progress report used on all orthodontic treatment patients to update patient and providers of treatment plan progress. This is particularly important for adult interdisciplinary dental therapy patients.



RETENTION/STABILIZATION CONFERENCE REPORT

TO:____________________ DATE:____________________

RE:____________________

Fixed orthodontic appliances were removed on________________; and________________has been referred back to you with the following observations and recommendations:

I. RETENTION PHASE:

Estimated Retention Time:____________________

Appliances Prescribed:

Maxillary:____________________

Mandibular:____________________

Frequency of Retention Recall:____________________

II. FUTURE TREATMENT CONSIDERATIONS:

Your patient,____________, has been advised to make an appointment with you to be evaluated for the following:

- ☐ Routine post-orthodontic examination and caries check:________________
- ☐ Cleaning/fluoride:________________
- ☐ Radiographic survey (as you see fit):________________
- ☐ Periodontal Evaluation:________________
- ☐ Restorative Treatment:________________
- ☐ Equilibration Needed:________________
- ☐ Future Extractions:________________
- ☒ Other: JAW GROWTH- for girls who are 15 and younger and boys who are 21 and younger, studies have shown that 5-8% of persons in this age group experience "late stage growth changes" that may affect the bite.

III. TREATMENT APPRAISAL:

Description of original problem and treatment objectives:________________

Limitations imposed by complexity of orthodontic problem:________________

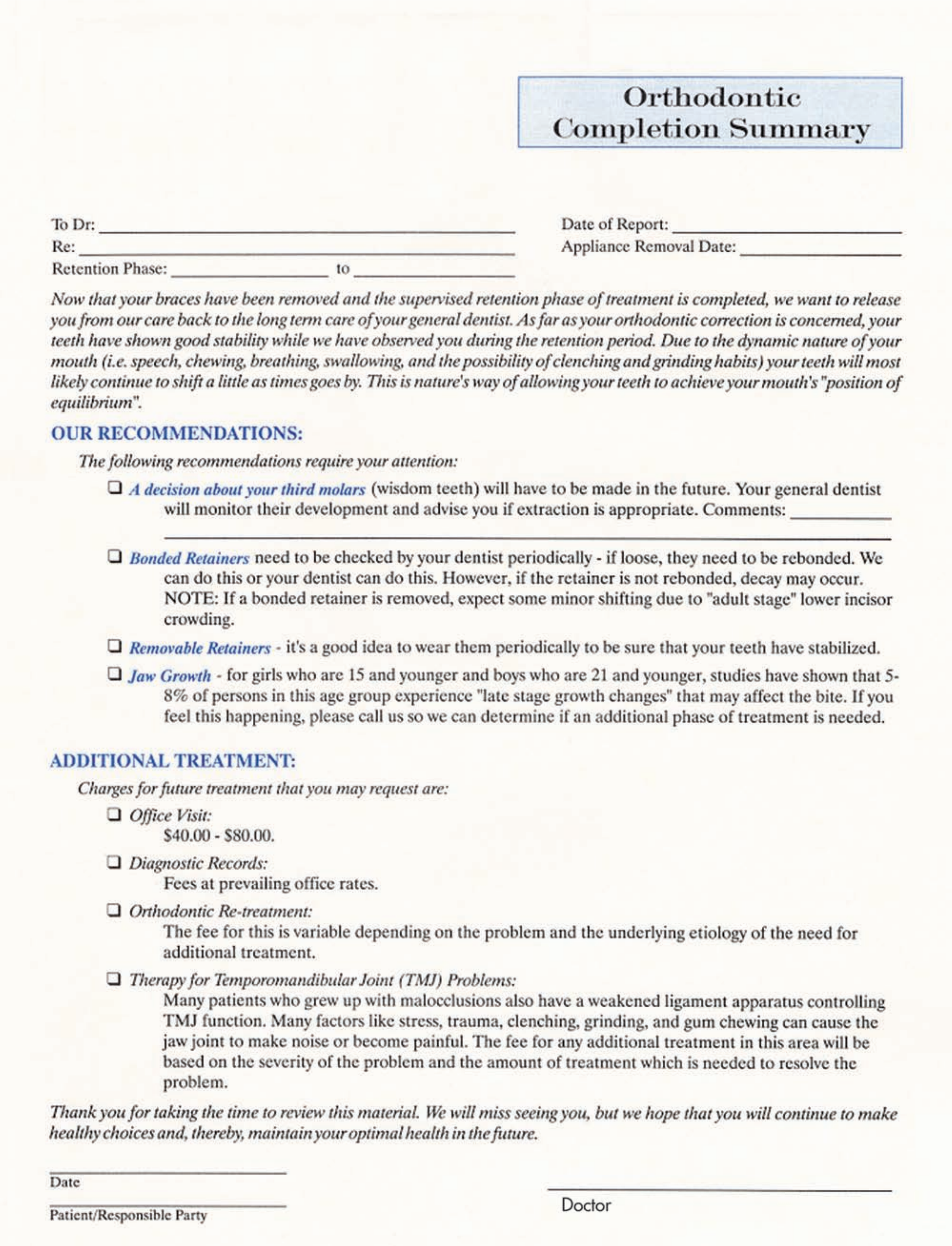
Limitations imposed by patient cooperation:________________

Overall assessment and comments:________________

If there are any questions regarding this report, please call me, at your earliest convenience.

Doctor

FIGURE 24-39 Retention/stabilization conference report used following adult interdisciplinary dental therapy to review treatment plan and future periodontal and restorative needs. Many times interdisciplinary treatment patients forget the sequence of who is doing what next. This is a great time to show orthodontic outcome and reinforce future treatment steps.



Orthodontic Completion Summary

To Dr: ______________________________ Date of Report: ______________

Re: ______________________________ Appliance Removal Date: ______________

Retention Phase: ____________ to ____________

Now that your braces have been removed and the supervised retention phase of treatment is completed, we want to release you from our care back to the long term care of your general dentist. As far as your orthodontic correction is concerned, your teeth have shown good stability while we have observed you during the retention period. Due to the dynamic nature of your mouth (i.e. speech, chewing, breathing, swallowing, and the possibility of clenching and grinding habits) your teeth will most likely continue to shift a little as times goes by. This is nature's way of allowing your teeth to achieve your mouth's "position of equilibrium".

OUR RECOMMENDATIONS:

The following recommendations require your attention:

- ☐ ***A decision about your third molars*** (wisdom teeth) will have to be made in the future. Your general dentist will monitor their development and advise you if extraction is appropriate. Comments: ____________
- ☐ ***Bonded Retainers*** need to be checked by your dentist periodically - if loose, they need to be rebonded. We can do this or your dentist can do this. However, if the retainer is not rebonded, decay may occur. NOTE: If a bonded retainer is removed, expect some minor shifting due to "adult stage" lower incisor crowding.
- ☐ ***Removable Retainers*** - it's a good idea to wear them periodically to be sure that your teeth have stabilized.
- ☐ ***Jaw Growth*** - for girls who are 15 and younger and boys who are 21 and younger, studies have shown that 5-8% of persons in this age group experience "late stage growth changes" that may affect the bite. If you feel this happening, please call us so we can determine if an additional phase of treatment is needed.

ADDITIONAL TREATMENT:

Charges for future treatment that you may request are:

- ☐ *Office Visit:*
  $40.00 - $80.00.
- ☐ *Diagnostic Records:*
  Fees at prevailing office rates.
- ☐ *Orthodontic Re-treatment:*
  The fee for this is variable depending on the problem and the underlying etiology of the need for additional treatment.
- ☐ *Therapy for Temporomandibular Joint (TMJ) Problems:*
  Many patients who grew up with malocclusions also have a weakened ligament apparatus controlling TMJ function. Many factors like stress, trauma, clenching, grinding, and gum chewing can cause the jaw joint to make noise or become painful. The fee for any additional treatment in this area will be based on the severity of the problem and the amount of treatment which is needed to resolve the problem.

Thank you for taking the time to review this material. We will miss seeing you, but we hope that you will continue to make healthy choices and, thereby, maintain your optimal health in the future.

____
Date

______________ ______________
Patient/Responsible Party Doctor

FIGURE 24-40 Completion conference report used 12 to 18 months after appliance removal for the orthodontist to complete the communication process with the patient and providers and to bring closure to the treatment retention phase. Without "formal closure," the patient may drop in anytime for ongoing treatment that may not be part of the initial orthodontic treatment plan.

assistance with the preparation of this chapter; without their outstanding professional input, this chapter would not be possible.

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CHAPTER 25

Orthodontic Aspects of Orthognathic Surgery

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OUTLINE

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Summary

BACKGROUND

The intrinsic genetic factors and extrinsic epigenetic factors affecting facial development are extremely complex, often leading to dental and skeletal imbalances that require interdisciplinary treatment plans to achieve a functional balance. The functional matrix hypothesis of Moss describes the many complex elements of facial development that must integrate to create the final form and function of the stomatognathic system.[1–3]

The development of the greatest amount of a patient's stomatognathic system occurs during the first 14 to 18 years of life, and its development occurs in the transverse, vertical, and sagittal dimensions.[4] When there are growth imbalances in the early stages of facial growth and development, the orthodontist takes the lead and makes a differential diagnosis and treatment planning decision; however, as the patient nears the end of his or her growth cycle and when there is evidence that the skeletal imbalance exceeds orthodontic/orthopedic capacity for correction, patient education and referral for surgical assessment become the next steps in the management of the patient's imbalanced system. This chapter will focus on current concepts of the teamwork necessary to diagnose and to treatment plan complex skeletal malocclusions.

Goals

Orthodontists and oral and maxillofacial surgeons must individualize goals of treatment for each adult patient through an interview process that takes place as part of the history and clinical examination and is continued when the records are reviewed in the treatment planning

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conference. Although achieving functional balance of the intricate stomatognathic system is generally the primary goal of therapy, aesthetic improvement is a natural component of balancing the bones and dentition that make up the chewing system. When treating patients with complex imbalances, we strive to achieve **f**unctional balance, using **r**eliable methods that achieve **r**ealistic, a**e**sthetic outcomes that are **e**conomically feasible. In addition, the orthodontist's/surgeon's teamwork also strives to provide a **s**table, **s**atisfactory relationship that enhances the overall orofacial **h**ealth of the patient. The acronym **FRESH** (Box 25-1) has been useful as a guide to describe the major goals of orthodontic/orthognathic treatment to patients considering this option.[5–8]

Although treatment goals among orthodontists and surgeons are generally consistent, many differences exist in the specific meanings of terms such as stability, facial balance, aesthetics, and even function.[34] For example, does the term *stability* always mean "without continual retention"? Is long-term mechanical retention to create stability acceptable, as suggested by Zachrisson and Buyukilmaz (Chapter 21)? Who is the judge of aesthetics: the orthodontist, the surgeon, the spouse or significant other, the parent, or the patient? Each of these important persons may judge differently the aesthetics of the profile, the smile, the tooth angulation, and the chin (see Chapters 2 and 3). In additional recent studies, Montini et al. found variation in perception of aesthetic improvement of profiles: "Data was gathered to see if Class II, mandibular deficient patients who had surgery had a more pleasing profile based on assessment by lay persons, orthodontists, and surgeons. Statistical results showed esthetic improvement was perceived for 13/14 silhouetted pairs of profiles. In some cases there were differences in perceived changes as judged by the different judges."[35]

In addition to this problem of a lack of uniform definitions or understanding of the terms used for accepted treatment objectives, the clinician with the patient often must *prioritize* those objectives. For example, a patient may have a moderate chewing problem and incipient myofascial imbalance caused by a lack of incisal function and a mild skeletal open bite (mandibular deficiency with maxillary protrusion) (Figure 25-1). The ideal treatment plan is orthodontic treatment and jaw surgery to achieve stability, function, and facial balance; a secondary plan may be the extraction of upper first premolars to close the bite. The functional goal is prioritized, but stability (extraction space rebound), vertical excess, and facial balance (change in the nasolabial angle) are compromised (deprioritized). Therefore, two prerequisites for achieving treatment goals and a successful outcome are:

1. A clear understanding of the patient's chief concerns and *the patient's* treatment goals, and

BOX 25-1 Orthodontic/Orthognathic Treatment Objectives Summarized by Acronym F.R.E.S.H.

Function—The fundamental goal of improving occlusal relationship is paramount; it is desirable to establish optimal gnathologic parameters for the stomatognathic system (incisal guidance, canine rise, balanced, bilateral posterior occlusal support) and TMJ health and TMJ stability without symptoms. [9,10]

Reliable—Utilization of methods of treatment that have been scientifically verified to be highly successful in achieving correction of skeletal imbalances and that are of lower risks than other available procedures for the improvement of a given condition.[11–13] Recent examples of techniques that have proven their reliability are: 1. Rigid fixation approaches[14]; 2. Jaw surgery to resolve sleep apnea[15–16]; and 3. Use of microscrews as anchorage to improve the range of nonsurgical treatment.[17]

Realistic—The plan of treatment has a high probability of correcting the patient's chief concern and offers the best option to achieve an outcome with a high probability of meeting both the patient's and doctors' expectations.[18–21]

Esthetics—Issues of aesthetics relates to both dental and facial appearance; facial aesthetics requires assessment of both the profile and frontal view to achieve soft tissue balance as well optimal symmetry. The facial balance should be present both statically and dynamically in speech and during facial expression, especially smiling. The role of the "aging process of the face" should also be integrated into the treatment planning process, especially when considering camouflage options.[8, 22–24]

Economic—The cost of the proposed treatment does require consideration because most patients have a budget for their medical and dental needs. With limited insurance for orthodontic care and reducing coverage for orthognathic surgical procedures, financial considerations frequently interfere with the optimal combined orthognathic/orthodontic treatment plan.[25]

Stability—A key part of the treatment outcome is ending with jaw and tooth positions that are reasonably stable. There are several dimensions–stability, and there are many adult orthodontic problems that require fixed retention–assure stability, especially of the lower and upper incisors[26,27] (also see Chapter 27).

Satisfaction—Achieving both patient and provider satisfaction is important. This usually occurs when there is open discussion, prior to treatment, about the goals that both doctor and patient are striving to achieve in this individual situation. This would include a frank discussion from the doctor about the "downside" or "limits" of the accepted plan. This is particularly true in cases that have a skeletal diagnosis and are being considered for camouflage therapy when skeletal correction is more ideal. The role of visualized treatment objectives and computerized predictions can assist the patient and the providers.[17,28,29]

Health—Includes periodontally healthy tissues, TMJ health, comfort and function, and emotional health. With complicated interdisciplinary treatments, it is important that the IDT teams work well together and are clear on the combined goals of therapy to provide optimal outcomes in these challenging cases. Treatment plans must always strive to preserve the healthy aspects of the case while improving those aspects that are diseased or nonfunctional.[30–33]

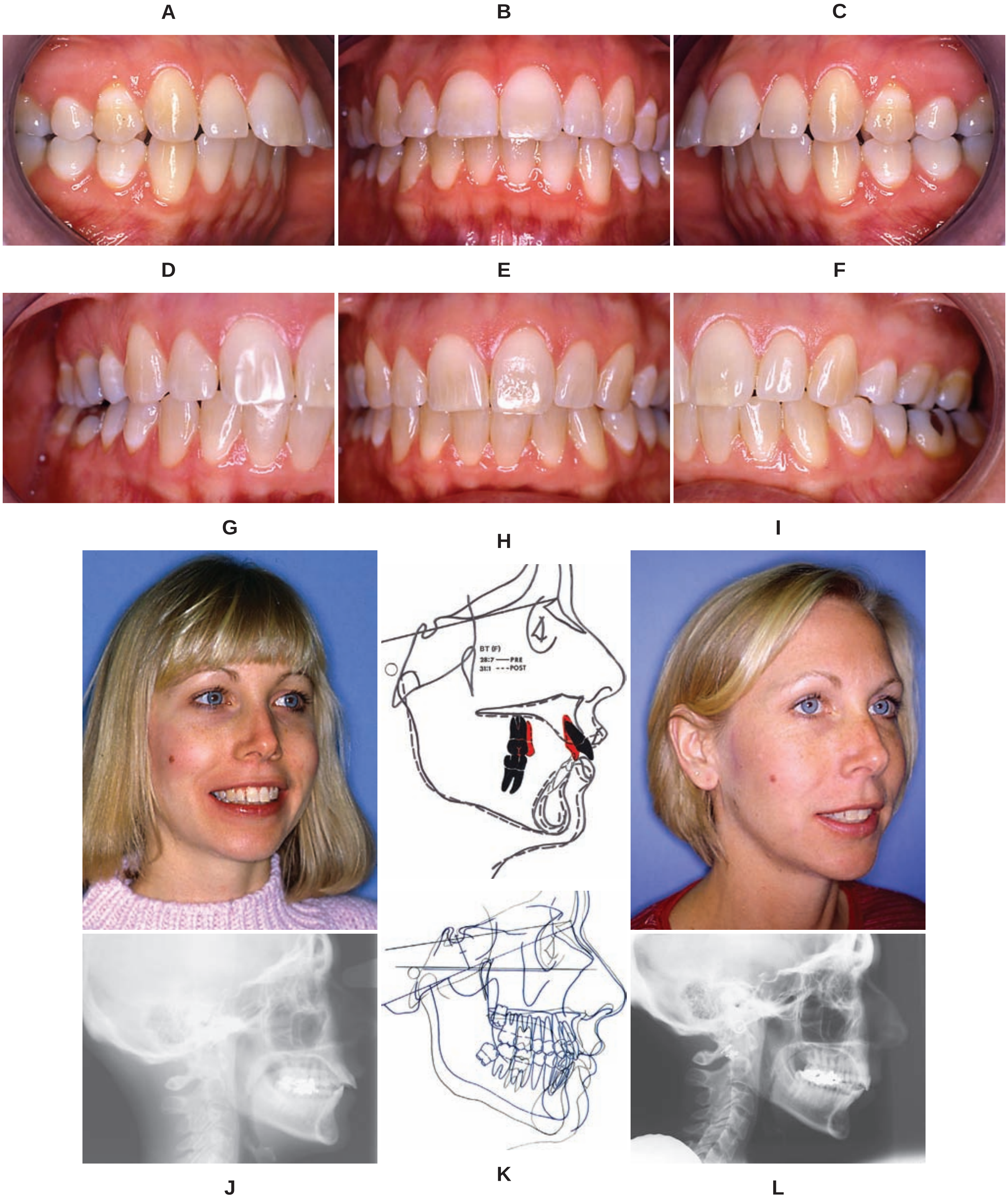

FIGURE 25-1 **A–C,** Pretreatment intraoral photographs showing Class II malocclusion (10.5-mm overjet). **D–F,** Long-term postorthodontic intraoral photographs 12 years after treatment completion showing good stability of orthodontic correction. **G,** Pretreatment facial smile photograph. **H,** Cephalometric superimposition of pretreatment tracing and posttreatment tracing showing successful Class II camouflage treatment. **I,** Long-term postorthodontic facial smile photograph, 12 years after treatment completion. **J,** Pretreatment lateral cephalogram radiograph. **K,** Bolton template-guided diagnosis showing maxillary skeletal and incisor protrusion and mandibular deficiency. Moderate skeletal imbalances in which both jaws contribute to dental protrusion are generally good candidates for camouflage treatment. **L,** Long-term postorthodontic lateral cephalogram radiograph, 12 years after treatment completion.

2. A clear explanation by the orthodontist of the treatment goals that can be achieved

This is especially true for patients with skeletal jaw malrelationships.[18] Ackerman, Profitt, and Nguyen in Chapter 1 of this text have properly described the process that most clearly allows clarification of goals (see Figures 1-7 and 1-8). The team, led by the orthodontist and the oral surgeon, carefully develops a problem list, which is reviewed with the patient; this provides an opportunity to discuss the treatment options for achieving the desired outcomes. The orthodontist informs the patient and family, and then all must agree on a plan that they believe will provide the best possible outcome with the least exposure to risk. The plan of action cannot be finalized until the other members of the provider team have contributed to the treatment plan and sequence. Careful integration of each team member's perspective helps to prevent last-minute surprises that can undermine the outcome and the patient's trust.

Current treatment planning approaches include significant patient participation requiring more of the practitioner's time and, at a humanistic level, more emphasis on educating the patient and less emphasis on arbitrary directives—for example "go to the surgeon for jaw surgery." From a risk management perspective, the steps in Proffit's problem-oriented approach (see Figures 1-7 and 1-8), if well documented, create a record that can assist the clinician should the patient subsequently initiate legal action. Machen[36] clarified that risk management is an important consideration when the orthodontist embarks on treatment using an *alternative plan*. As described here, the orthodontist started treatment with the plan of mandibular advancement for the Class II patient. During treatment the patient decided against the recommended jaw surgery and proceeded to have camouflage therapy with the upper first premolars extracted. During protrusion reduction and extraction space closure, the patient developed temporomandibular joint (TMJ) symptoms and eventually sued the orthodontist.

In evaluating this case, several factors appear to have been deemed important by the jury in determining that the practitioner fulfilled his obligations to the patient. First, the practitioner performed a complete evaluation and suggested a course of treatment designed to correct the patient's problem. Second, an alternative plan was made available that was clearly identified as a compromise. Third, the potential risks and complications associated with the alternative treatment were presented to, discussed with, and acknowledged by the patient. And, finally, a paper trail existed confirming each of the above-mentioned steps.

Following the steps referenced in Figures 1-7 and 1-8 may seem time consuming, but doing so will prove invaluable because the technologic capabilities now available for changing the form and function of the stomatognathic system are profound and require judicious care in their use (Figure 25-2). With orthognathic surgical insurance coverage unavailable in many situations, clarification of the treatment plan options with an explanation of the risks and benefits is more critical than ever.

NEED VERSUS DEMAND

Stomatognathic system imbalances are generally not life threatening, which places their need for treatment into a category of "elective." However, since imbalances in the stomatognathic system can have a major negative impact on one's masticatory function, muscle comfort, dental health, facial aesthetics, and self-esteem, proper treatment is very important to each individual patient.

Because orthodontic-orthognathic treatments of skeletal dysplasias are elective procedures in most cases, further discussion of need and demand considerations is warranted. Proffit and White[37,38] helped to clarify this discussion with the following statement: "The indication for surgical-orthodontic treatment is that a skeletal or dentoalveolar deformity is so severe that the magnitude of the problem lies outside the envelope of possible correction by orthodontics alone." An arbitrary "envelope of discrepancy" (see Figure 1-6) was developed to illustrate the concept of limitations of various treatment modalities.[39]

Orthodontic Retreatment and Skeletal Malocclusions

The main problem with many orthodontic patients who required retreatment appeared to be significant differential growth that led to Class II open bites, maxillomandibular transverse discrepancies with posterior crossbites, or Class III type occlusal problems[40] (Box 25-2). As specialists, orthodontists know that these are difficult growth patterns to manage. Although many of these malocclusions can be corrected with orthopedics and good compliance, many cannot. Therefore, the orthodontist is obliged to diagnose in all three planes of space, to discuss therapeutic modifiability of skeletal imbalances openly, and to present the possibility of a surgical phase if compliance or the growth response is inadequate to achieve an optimal occlusal result with acceptable facial balance. In many of these cases, cephalometric reassessment of therapeutic response is important.

It becomes critical in these cases to communicate more clearly about treatment progress, treatment outcome, and the risks of instability. To refine communication systems so that trained administrative and clinical staff can step into the "treatment coordinator" role at any patient appointment to discuss the various stages of treatment with the patient/parent is advantageous. The communication system should provide a

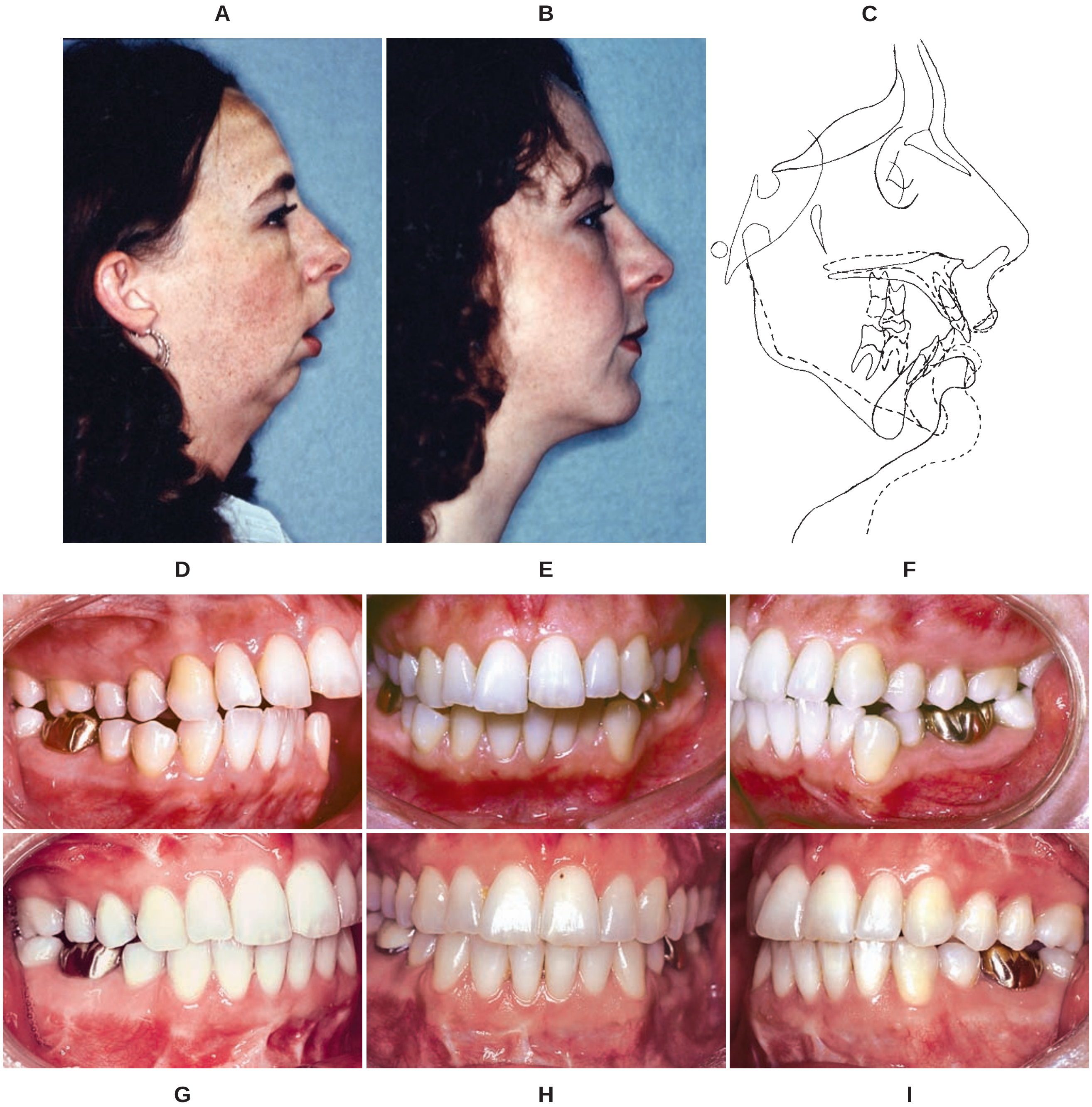

FIGURE 25-2 **A,** Presurgical profile photograph showing severe mandibular and chin deficiency. **B,** Postsurgical profile photograph showing correction of mandibular and chin deficiency. **C,** Superimposition of lateral cephalogram tracing (*solid lines* represent pretreatment appearance; *dashed lines* represent posttreatment appearance). **D–F,** Presurgical intraoral photographs showing severe malocclusion. **G–I,** Posttreatment intraoral photographs showing occlusal correction through orthodontics and jaw surgery.

standardized office protocol for the conference and report process with patients/parents and the family dentist, pediatric dentist, or periodontist. Within the recommended communication process are four conference reports that are recommended and serve as "milestones" in the treatment/communication process:

1. Treatment planning conference report (to finalize the treatment planning process and document treatment goals; see Figure 24-30)
2. Progress conference report (sent to family dentist with panoramic radiograph and any other appropriate growth evaluation records; see Figure 24-34)
3. Stabilization/retention conference report (to discuss treatment successes and treatment shortcomings and to highlight patients at high risk for needed additional treatment; see Figure 24-35)
4. Treatment completion conference (to review treatment results and prepare patient for postretention requirements; see Figure 24-36)

BOX 25-2 Sequence of Treatment for Patients with Significant Dentofacial Imbalances

1. Multiple provider team selection
   - Orthodontist
   - Periodontist
   - Restorative dentist
   - Oral surgeon
   - Psychologist
2. Goal clarification for team members
   - Functional occlusion
   - Reliable methods
   - Stability
   - Health
   - Aesthetics
3. Clinical awareness of dentofacial deformity
   - Self, general dentist, friend
4. General assessment of patient
   - A good candidate?
   - Periodontal status
5. Evaluation of preliminary records by the dental team
   - Splint therapy for diagnosis of temporomandibular dysfunction, if needed
6. Completion of diagnostic records
   - May include lifestyle assessment by clinical psychologist
   - May require more sophisticated temporomandibular joint studies
7. Multidisciplinary review of dentofacial problem based on patient records
8. Explanation to patient of available treatment options
   - Optimal treatment plan
   - Alternatives
9. Consultation with patient and significant other by dental team providers
   - Risk-benefit ratio
   - Fees and insurance coverage
   - Treatment time
   - Other concerns
10. Patient acceptance of treatment plan
11. Comprehensive orthodontic treatment (usually for 8 to 18 months before surgery)
    - Orthodontic movement to decompensate tooth positions
    - Coordination of arches in anticipation of surgical repositioning
    - Alignment of teeth and correction of rotations
12. Presurgical reevaluation records
    - Complete records
    - Prediction tracing (detailed movements planned)
    - Model surgery (reviewed by orthodontist and surgeon)
    - Determination of specific fixation needs
    - Patient-spouse review with orthodontist and surgeon
    - Reevaluation by psychologist
13. Orthognathic surgery
    - Simplest procedure or procedures to achieve professional goals and satisfy patient's needs
14. Postsurgical period
    - Early: 2 to 3 weeks of fixation
    - Late: 3 to 8 weeks of fixation
    - Reevaluation of surgical procedure
    - Meeting between patient and psychologist for update and support
15. Evaluation of surgical stability
    - Orthodontic finishing, occlusal adjustments, and retention procedures
    - Optimal continuation of contact with psychologist
16. Posttreatment records
    - 1 year posttreatment
    - Reevaluation with dental team, especially oral surgeon and psychologist
17. Treatment experience (used in management of future cases)
    - Positive reinforcement
    - Problem solving
    - Reevaluation of degree of success in achieving goals
    - Treatment evaluations by patient and all providers

This formal, predictable conference system provides information that patients, parents, and dentists appreciate. More important, the conference system is a mechanism that minimizes miscommunication, particularly in complicated cases that without proper documentation could lead to adverse legal action. This communication system is particularly relevant in skeletal imbalance cases in which the orthodontic plan may be "heroic" and only achievable with excellent growth response and excellent cooperation. This process also "conditions" the patient and parent to the possible need for retreatment or more advanced treatment including braces and jaw surgery.

The patient in Figure 25-3 illustrates a patient for whom orthodontic/orthopedic therapy was initially attempted, but her mandibular growth excess exceeded the capacity to orthopedically modify the maxilla's growth to create a balanced occlusion. The preferred treatment was then to wait for growth cessation and provide a surgical solution. The number of patients *needing and demanding* orthodontic/orthognathic correction is increasing with population increases and awareness (Tables 25-1 to 25-3). The following list identifies the categories of patients for whom orthodontists and oral and maxillofacial surgeons will continue to provide advanced management through the refined techniques of orthodontics/orthopedics, and in many cases, orthognathic surgery:

- Genetic growth imbalances beyond the orthodontic/orthopedic range of correction (see Tables 25-1 to 25-3)
- Facial trauma causing growth alterations
- Orthodontic retreatment problems that grew outside the range of conventional orthodontic correction
- Patients with sleep apnea disorders that require orthognathic procedures to completely resolve

TABLE 25-1 Estimated Prevalence of Mandibular Deficiency Severe Enough to Indicate Surgery

	Percentage	Number
Prevalence of skeletal Class II malocclusion	10*	22.5
At appropriate age for surgical treatment	68	4,625,000
Severe enough to warrant surgery	5	731,250
Mandibular advancement	70	510,000
Maxillary setback	10	67,500
Both	20	145,000
New patients added to population yearly[†]	0.5	21,250

*Assuming a U.S. population of 325 million.
†Assuming 4.25 million live births per year.

TABLE 25-2 Estimated Prevalence of Class III Problems Severe Enough to Indicate Surgery

	Percentage	Number
Prevalence of skeletal Class III malocclusion	0.6*	1.35 million
At appropriate age for surgical treatment	65	877,500
Severe enough to warrant surgery	33	290,000
Mandibular setback	45	130,000
Maxillary advancement	35	101,000
Both	20	58,000
New patients added to population yearly[†]	0.2	8,500

*Assuming a U.S. population of 325 million.
†Assuming 4.25 million live births per year.

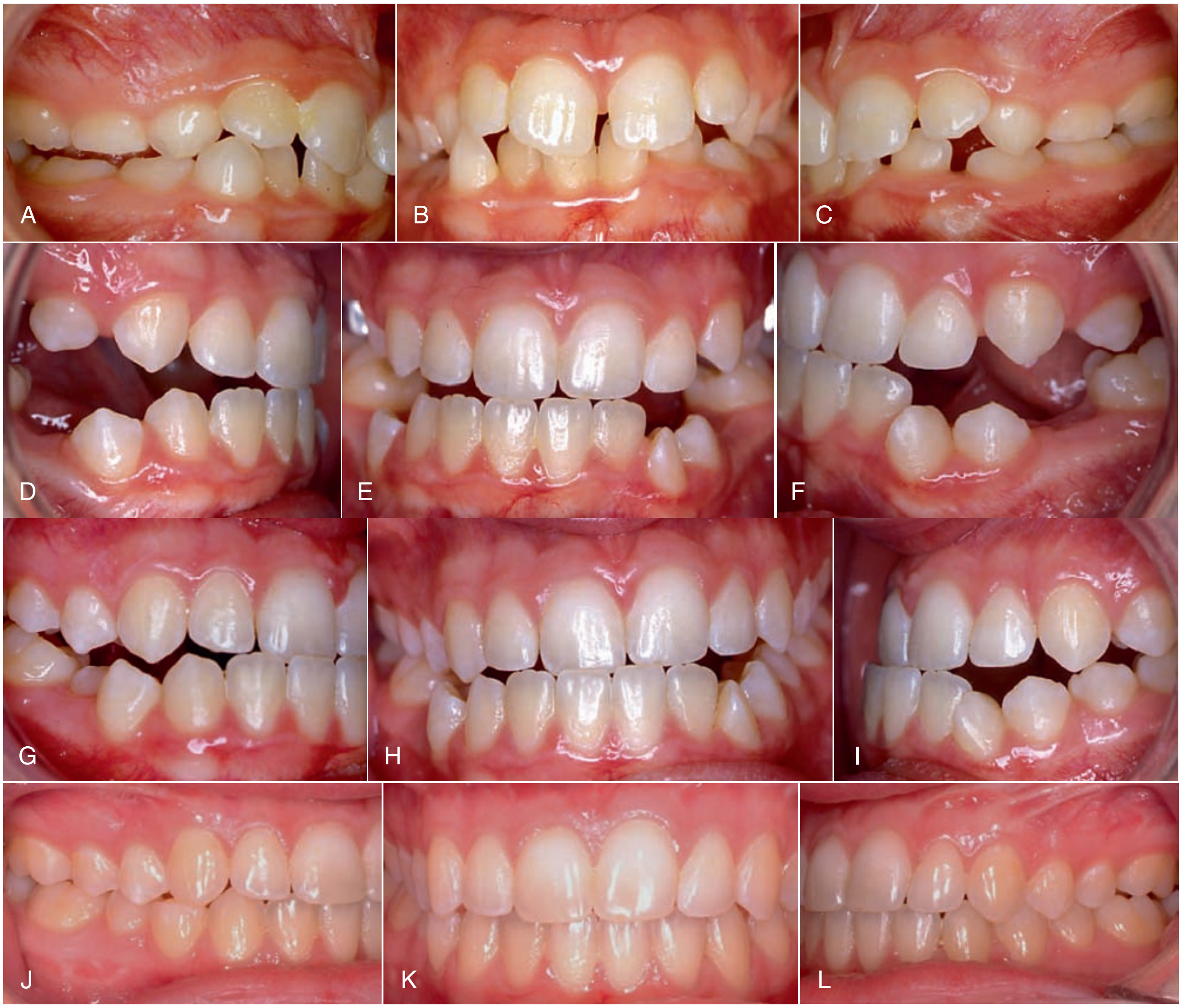

FIGURE 25-3 **A–C,** Patient at age 9y 11m: Intraoral photographs prior to any orthodontic treatment. **D–F,** Patient at age 13y 1m: Intraoral photographs following phase I expansion with Class III intraoral traction. **G–I,** Patient at age 14y 11m: Intraoral photographs illustrating bite change secondary to adolescent growth spurt, greater Class III jaw imbalance with increasing asymmetry to right. **J–L,** Patient at age 17y 4m: Intraoral photographs following orthodontic arch preparation and maxillo-mandibular jaw surgery to resolve the maxillary deficiency and mandibular excess with asymmetry.

Continued

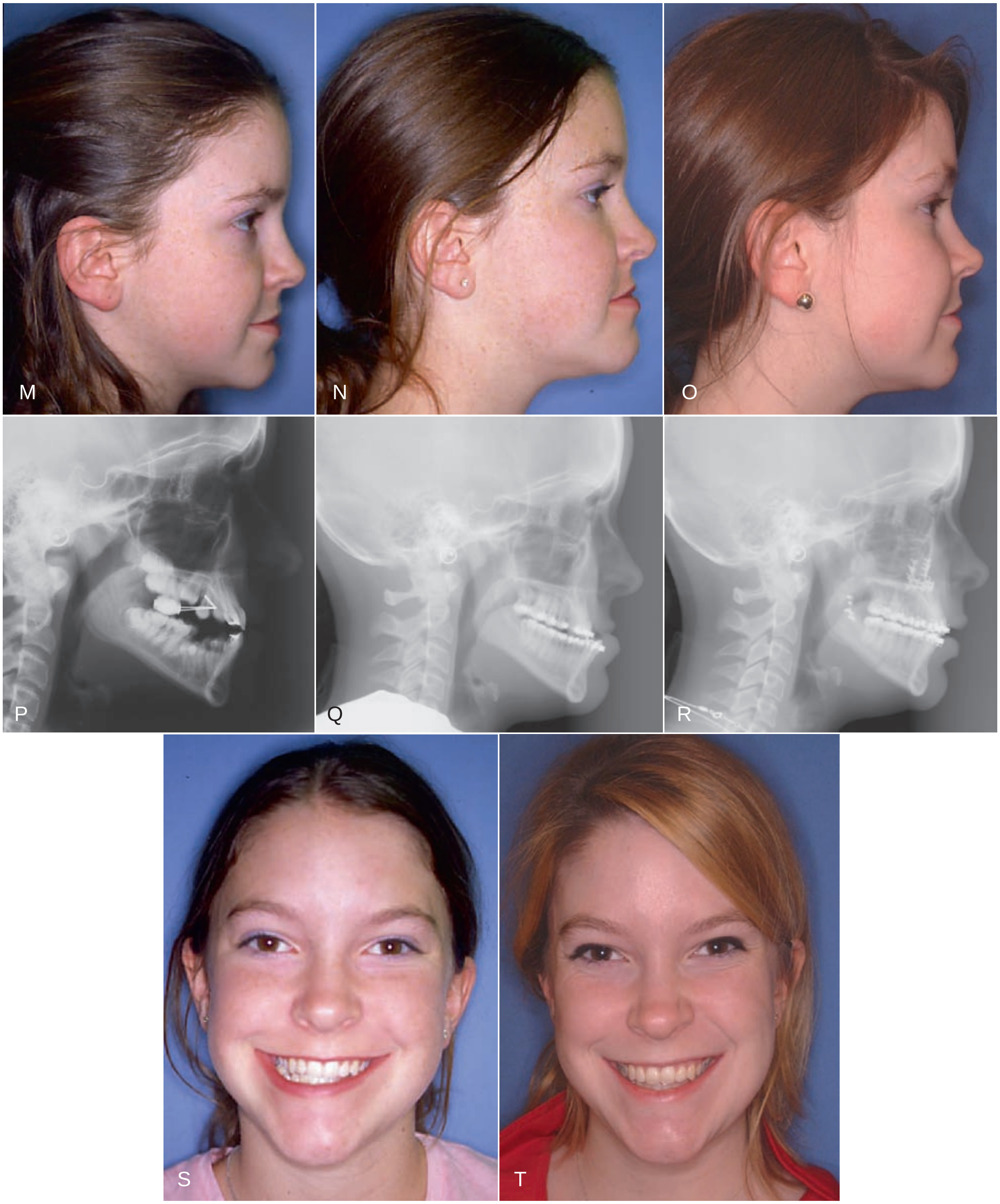

FIGURE 25-3, cont'd **M** and **P,** Profile facial view, lateral view of cephalogram at age 9y 1m, respectively. **N** and **Q,** Profile view, lateral view of cephalogram at age 16y 1m, respectively. **O** and **R,** Profile view, lateral view of cephalogram at age 17y 4m, respectively. **S,** Frontal facial smile photograph at age 14y 8 m, prior to initiating presurgical orthodontic treatment. **T,** Frontal facial smile photograph at age 17y 4m, after orthodontics and maxillo-mandibular surgery.

TABLE 25-3 Estimated Prevalence of Long-Face Problems Severe Enough to Indicate Surgery

	Percentage	Number
Prevalence of severe anterior open bite	0.6*	1.35 million
At appropriate age for surgical treatment	65	877,500
Severe enough to warrant surgery (superior repositioning of the maxilla)	25	220,000
New patients added to the population yearly†	0.2	6,375

*Assuming a U.S. population of 325 million.
†Assuming 4.25 million live births per year.

TECHNOLOGIC ADVANCES IN ORTHOGNATHIC SURGERY

Advances in medical management and surgical techniques have improved the predictability of favorable outcomes and improved functional and aesthetic results for patients undergoing orthognathic surgery. This section presents a brief discussion of medical advances, which will include anesthetic technique and edema, nausea, and infection control. Surgical advances are discussed and include surgical procedures and treatments as well as fixation techniques.

Medical Advances

Hypotensive anesthesia has been well documented to decrease blood loss during orthognathic surgery.[41–43] The technique is sufficiently flexible that a variety of medications can be used to achieve the desired effect. The determination of which medications are used is based on the patient's medical history and the anesthesiologist for the case. Hypotensive anesthesia allows the surgeon to perform complicated orthognathic procedures in highly vascular areas with minimal blood loss.[44] This technique has reduced the need for blood transfusion, and the lower blood loss has been shown to be a significant factor for a decreased length of stay in the hospital.[45]

Edema control is essential to allow a quick return to normal function. Measures for controlling edema include (1) minimizing surgical trauma, (2) shortening operating time, (3) maintaining careful hemostasis, and (4) ensuring pharmacologic control of the inflammation process. Pharmacologic control is achieved primarily through the use of corticosteroids. Although corticosteroids can affect leukocyte function adversely, short-term use shows minimal negative effect. Commonly used corticosteroids include methylprednisolone and decadron.

Nausea is the most common postoperative complication after orthognathic surgery and general anesthesia.[46] Nausea can lead to an increase in hospital stay as well as medical issues such as dehydration. Nausea can also lead to poor patient satisfaction. Silva et al.[46] found that the following factors are associated with an increased risk of postoperative nausea and vomiting:

1. Female gender
2. Young patients (15 to 25 years old)
3. Nonsmoking status
4. Presence of predisposing factors (prior history of nausea/vomiting or motion sickness, vertigo, migraine headaches)
5. Use of volatile general anesthetics
6. Maxillary surgery
7. Postoperative pain level in PACU
8. Use of postoperative analgesic opioid drugs

Infection is an uncommon occurrence after orthognathic procedures.[47] The incidence of infection is decreased with antibiotic use preoperatively and postoperatively.[48,49] However, when infection does develop, it usually is a local inflammation that responds well to incision and drainage and systemic antibiotics. Prophylactic antibiotics still are used; commonly 1 million units of penicillin are administered intravenously just before surgery and again every 6 hours for 2 days after surgery. Cefazolin (Kefzol), clindamycin, and amoxicillin-clavulanate can be used as alternatives to penicillin G.

Surgical Advances

Oral and maxillofacial surgeons have studied the effects of a variety of surgical techniques over the past 20 years. The following criteria generally are considered in determining which technique best serves the patient's needs:

- Safety of the technique
- Reduced morbidity (neurologic and vascular)
- Stability of the procedure
- Enhanced rate of healing
- Reduced surgical time under anesthesia

Figures 25-3 to 25-13 show schematic illustrations of some of the more common and considered conventional surgical procedures currently used to correct skeletal malocclusions. Wolford changed a key approach when he presented the benefits of occlusal plane changes in orthognathic surgery.[50] Since that time, orthognathic procedures with occlusal plane change components have become more common and have received more notoriety due to their benefits in treatment planning. This technique allows surgeons to address both the functional and aesthetic concerns of a patient.[51] For example, classic orthognathic surgery would not move the occlusal plane in a

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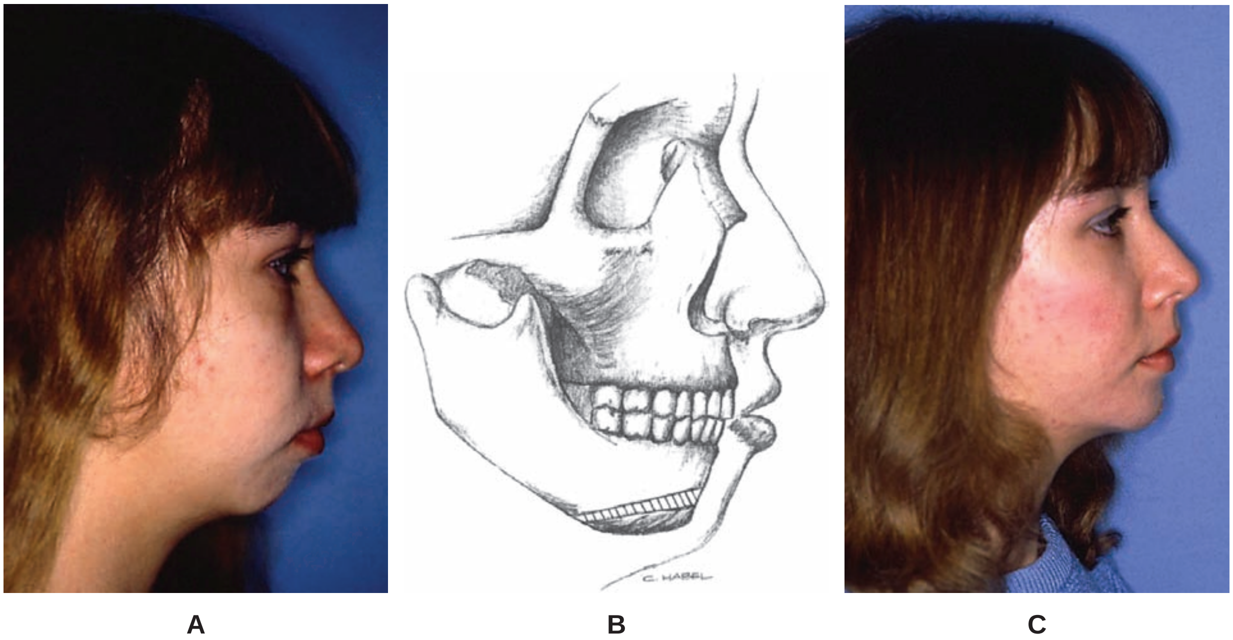


FIGURE 25-4 **A,** Problem: horizontal deficiency and vertical chin excess before treatment. **B,** Schematic of surgical procedure: vertical reduction with anterior advancement of the chin. **C,** Orthodontic/surgical outcome: results after combination therapy (i.e., orthodontics and chin surgery). *(Surgery by M. Steichen, Arlington Heights, IL.)*

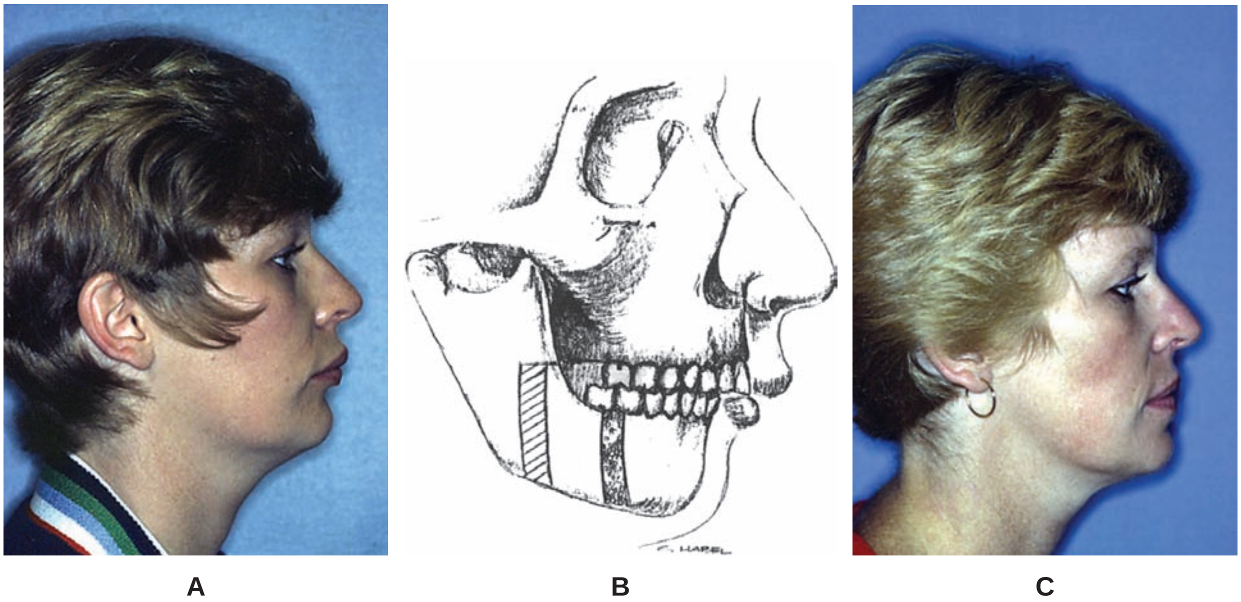


FIGURE 25-5 **A,** Problem: Class II mandibular deficiency before treatment. **B,** Schematic of surgical procedure: sagittal split osteotomy with advancement. **C,** Orthodontic/surgical outcome: results after combination therapy. *(Surgery by A. Frer, Schaumburg, IL.)*

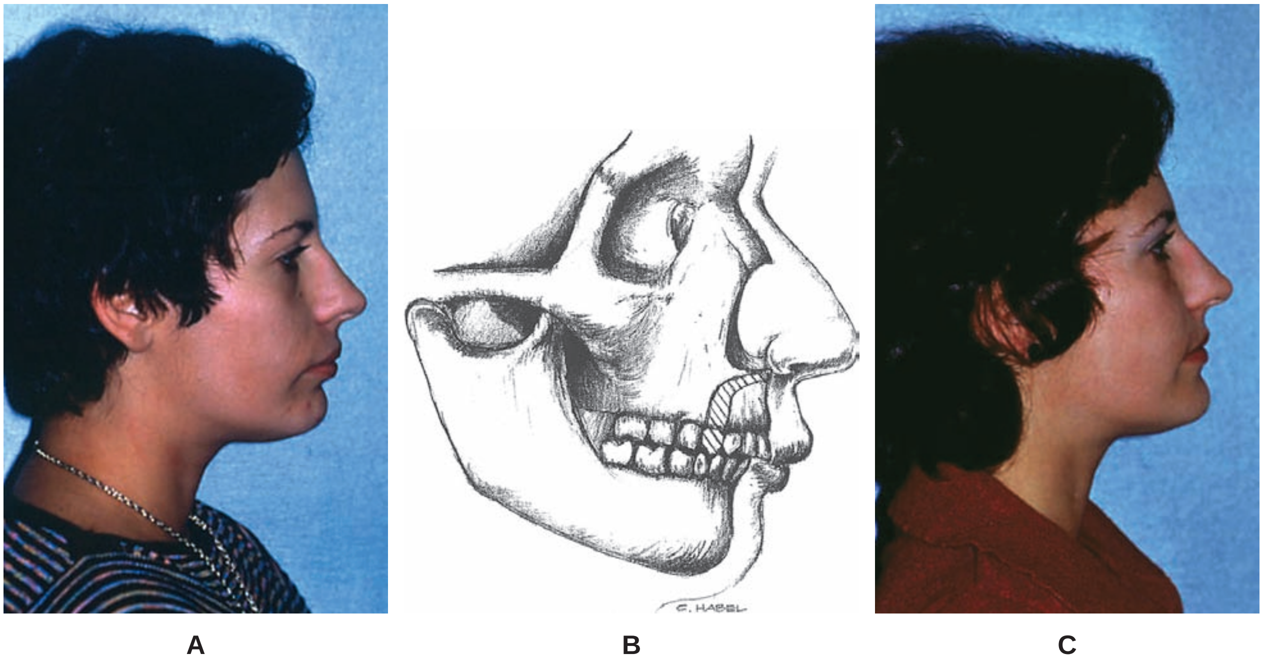


FIGURE 25-6 **A,** Problem: Class II maxillary protrusion before treatment. **B,** Schematic of surgical procedure: segmental setback of the maxillary anterior teeth. **C,** Orthodontic/surgical outcome: results after combination therapy. *(Surgery by A. Frer, Schaumburg, IL.)*

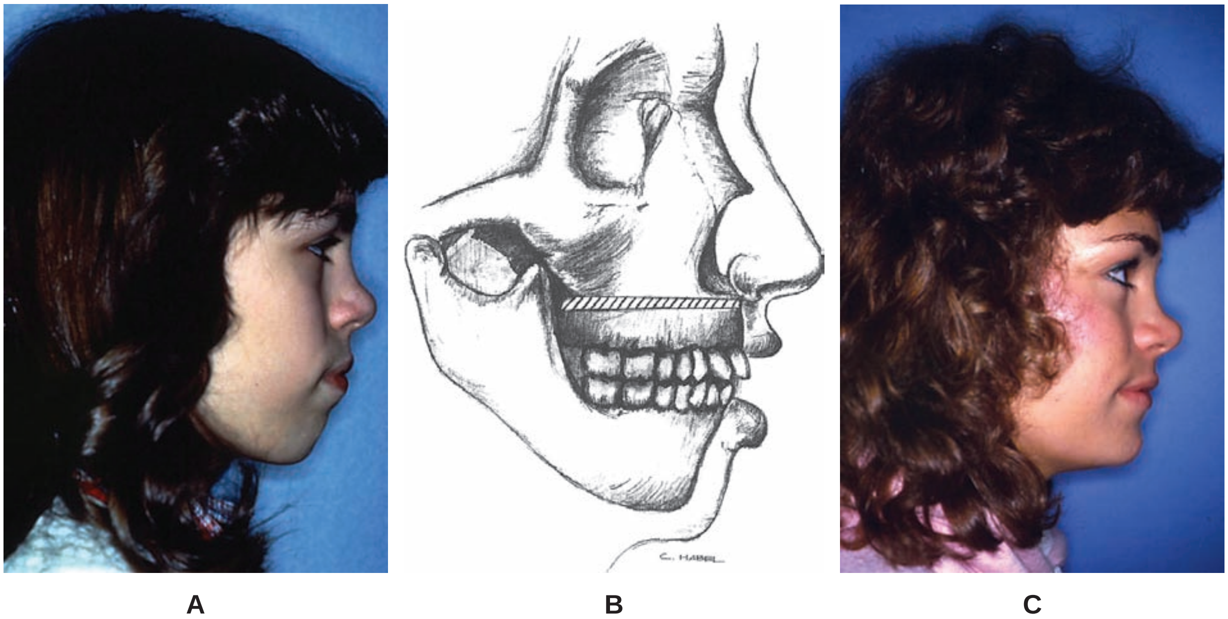


FIGURE 25-7 **A,** Problem: excess vertical growth of the maxilla and down and back rotation of the mandible before treatment. The Le Fort osteotomy has a number of modifications, has proved to be safe, and has a high degree of stability. Excess vertical maxillary growth is one problem that is readily solved with a Le Fort procedure. **B,** Schematic of surgical procedure: Le Fort osteotomy with maxillary impaction to impact the maxilla and an advancement genioplasty identical to that depicted in Figure 25-4, *B*, was performed. **C,** Orthodontic/surgical outcome: results after combination therapy. *(Surgery by P. T. Akers, Glenview, IL.)*

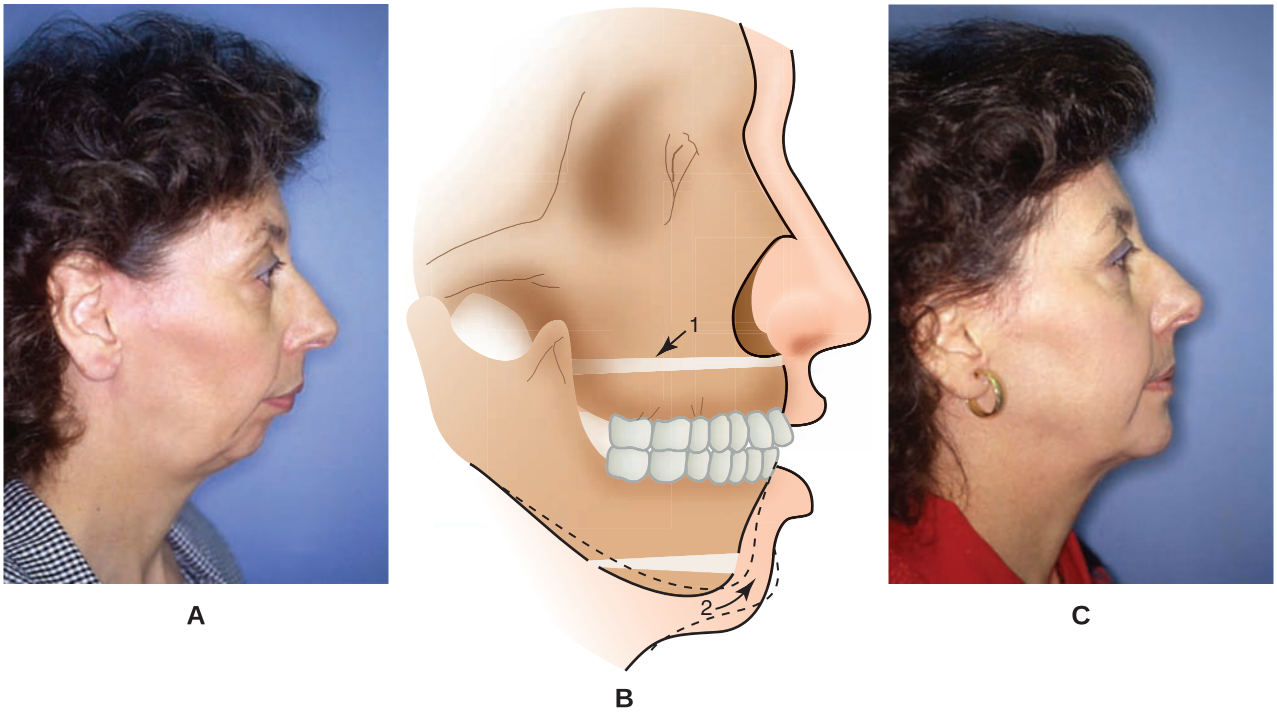


FIGURE 25-8 **A,** Problem: Class II mandibular deficiency type III (high mandibular plane angle) before treatment. **B,** Schematic of surgical procedure: maxillary open-bite osteotomy (*arrow 1*), mandibular osteotomy (*arrow 2*), and osteotomy of chin (*arrow 3*). **C,** Orthodontic/surgical outcome: results after combination therapy. *(Surgery by P. T. Akers and L. McCarthy, Glenview, IL.)*

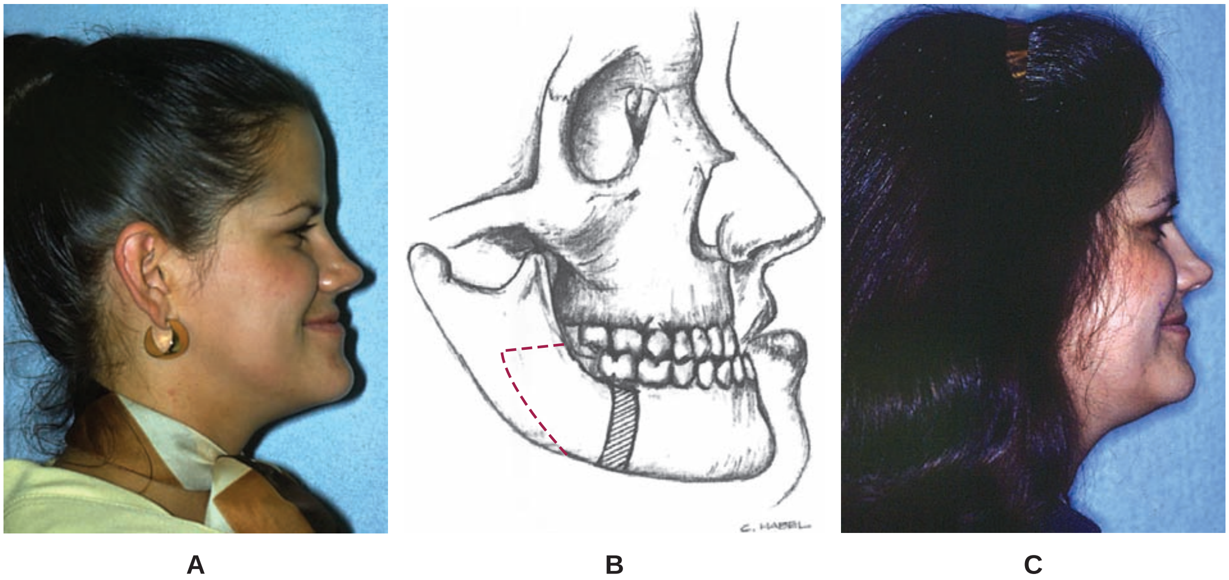


FIGURE 25-9 **A,** Problem: Class III mandibular excess before treatment. **B,** Schematic of surgical procedure: sagittal split osteotomy with setback (shown). Subcondylar vertical osteotomy (not shown). **C,** Orthodontic/surgical outcome: results after combination therapy. *(Surgery by G. Doerfler, Glen Ellyn, Ill.)*

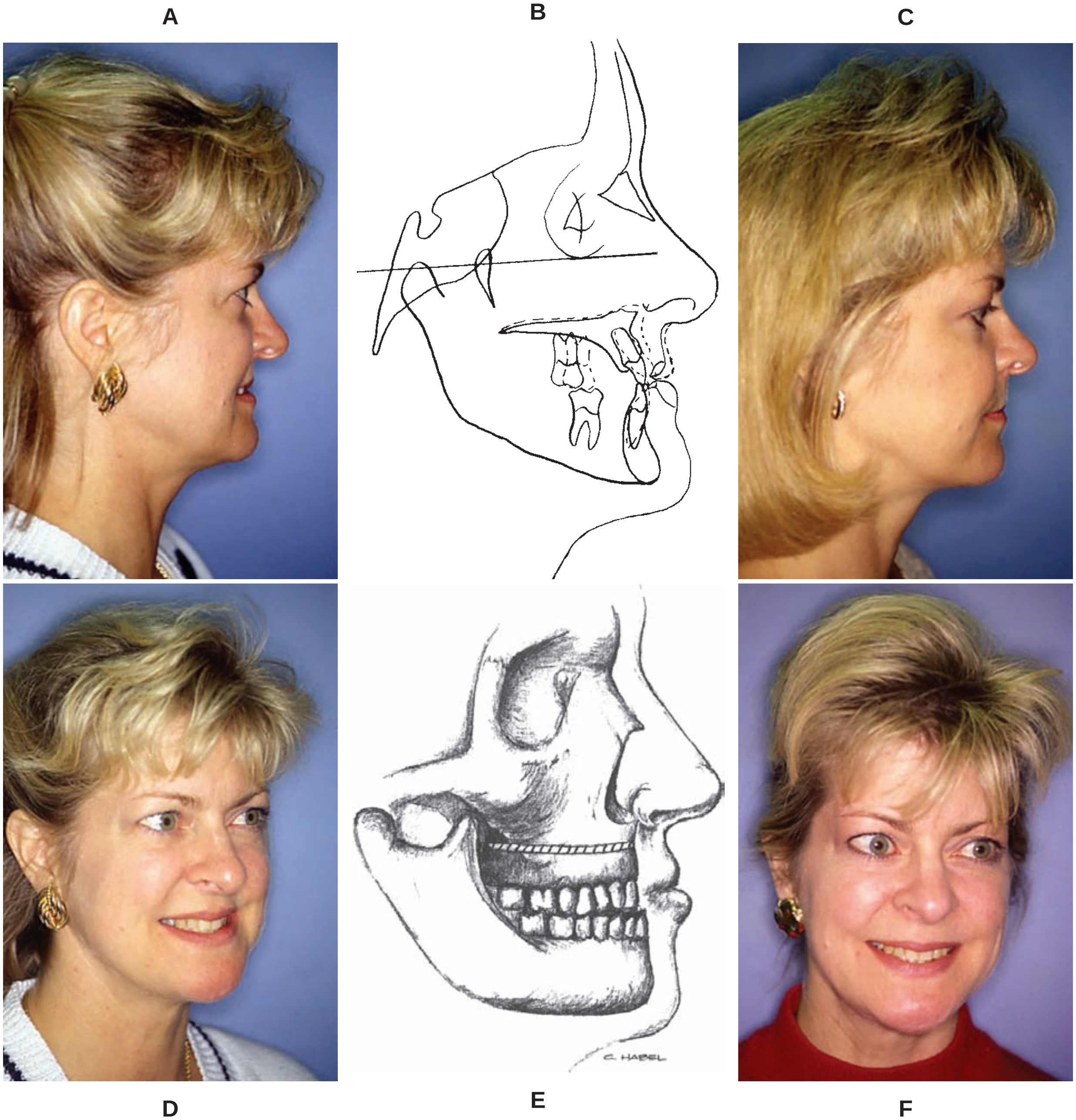


FIGURE 25-10 **A,** Problem: Class III maxillary horizontal deficiency before treatment. **B,** Cephalometric superimposition showing pretreatment and posttreatment results. **C,** Orthodontic/surgical outcome: results after combination therapy. Note reversal of facial aging because upper lip is more supported as a result of maxillary advancement. **D,** Pretreatment facial smile showing Class III maxillary horizontal deficiency. **E,** Schematic of surgical procedure: Le Fort osteotomy with maxillary advancement. **F,** Posttreatment facial smile showing corrected skeletal deficiency.

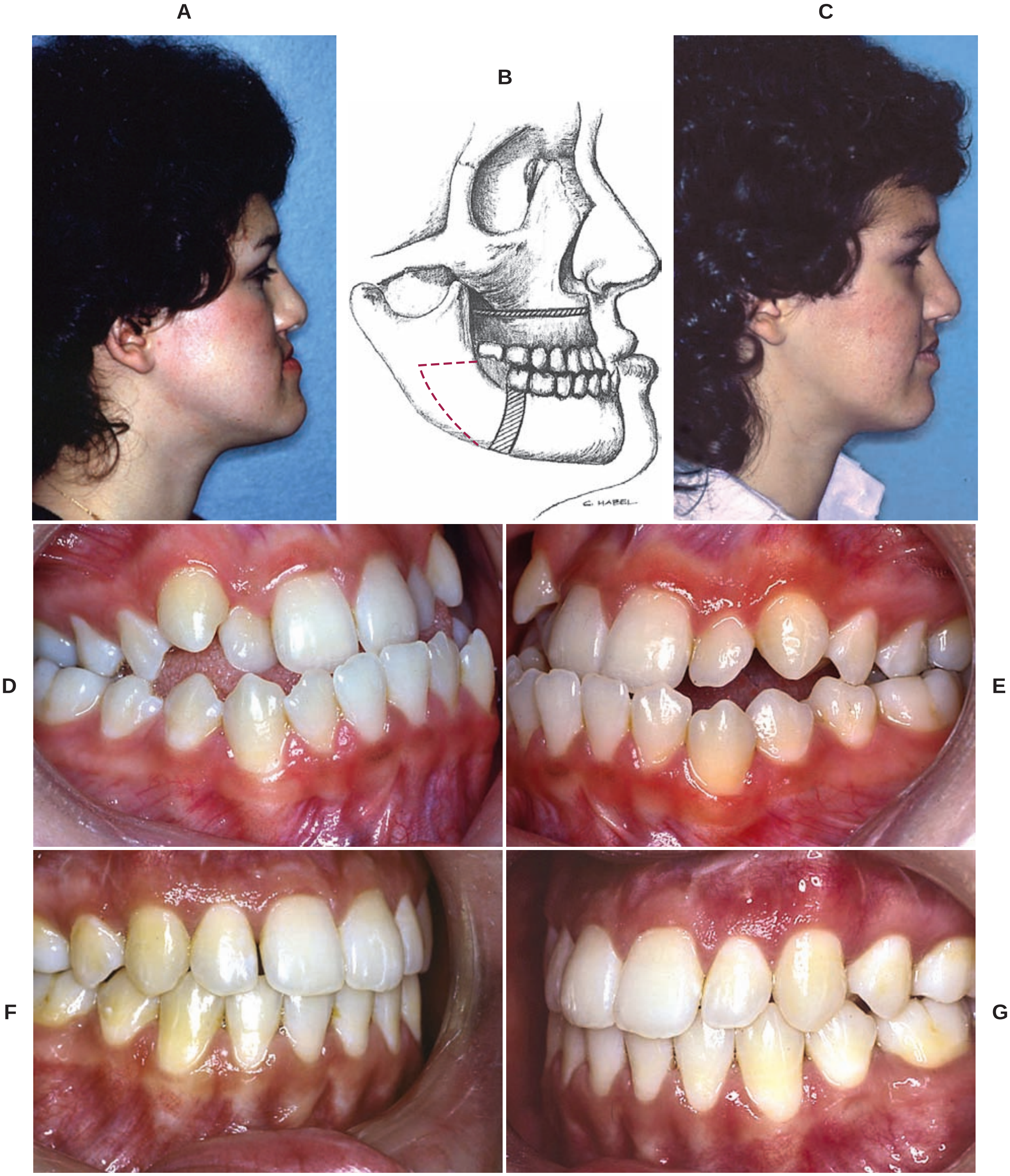


FIGURE 25-11 **A,** Problem: Class III maxillary deficiency and mandibular excess before treatment. **B,** Schematic of surgical procedure: Le Fort osteotomy of the maxilla to advance or impact (or both) and sagittal split osteotomy of the mandible to set back. **C,** Orthodontic/surgical outcome: results after combination therapy. **D, E,** Pretreatment intraoral photographs illustrating severe Class III malocclusion. **F, G,** Posttreatment intraoral photographs following extraction of No. 4, No. 13, No. 20, and No. 29; orthodontics alignment and decompensation; and maxillary advancement and mandibular setback. *(Surgery by A. Frer, Schaumburg, IL.)*

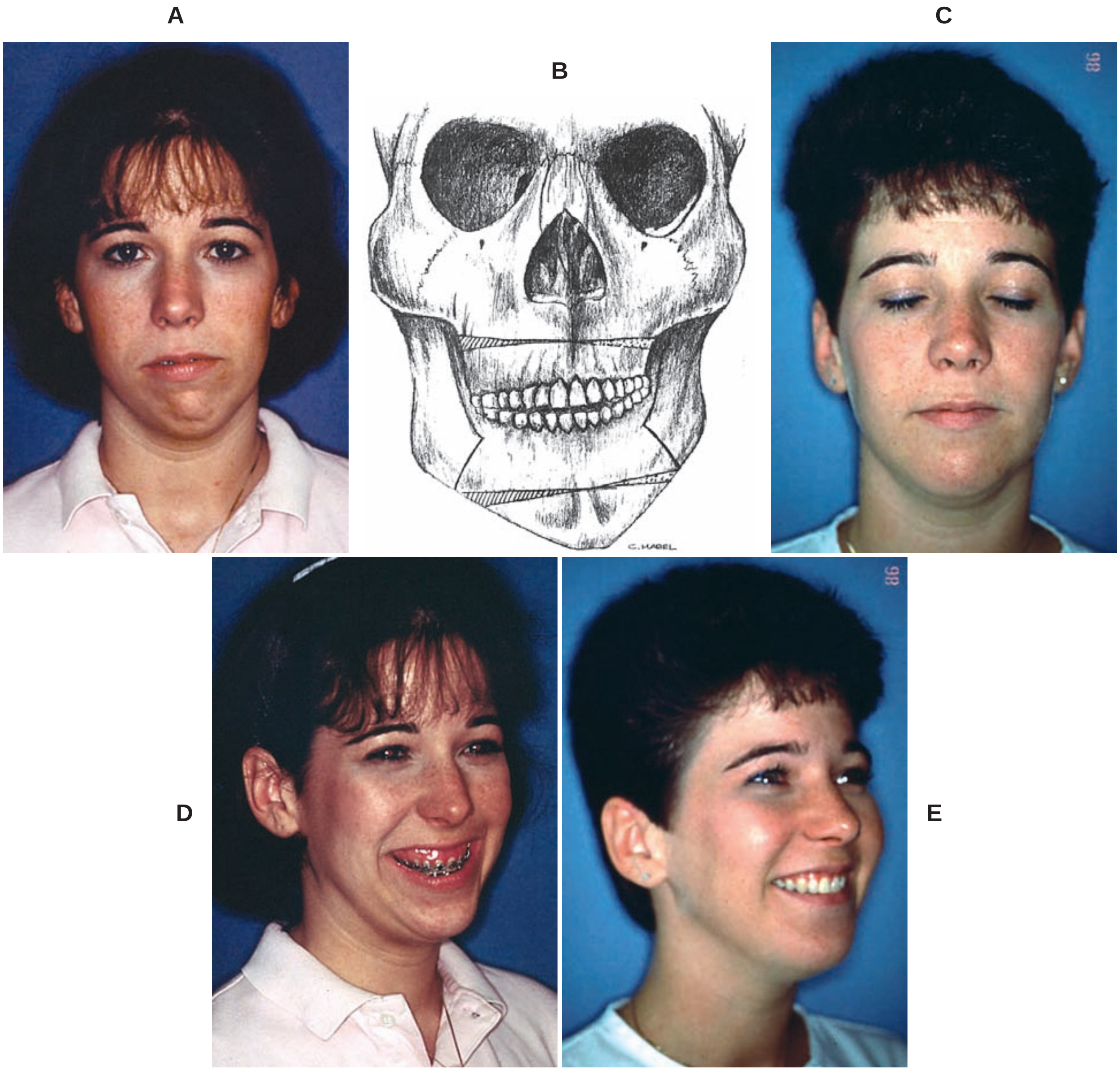
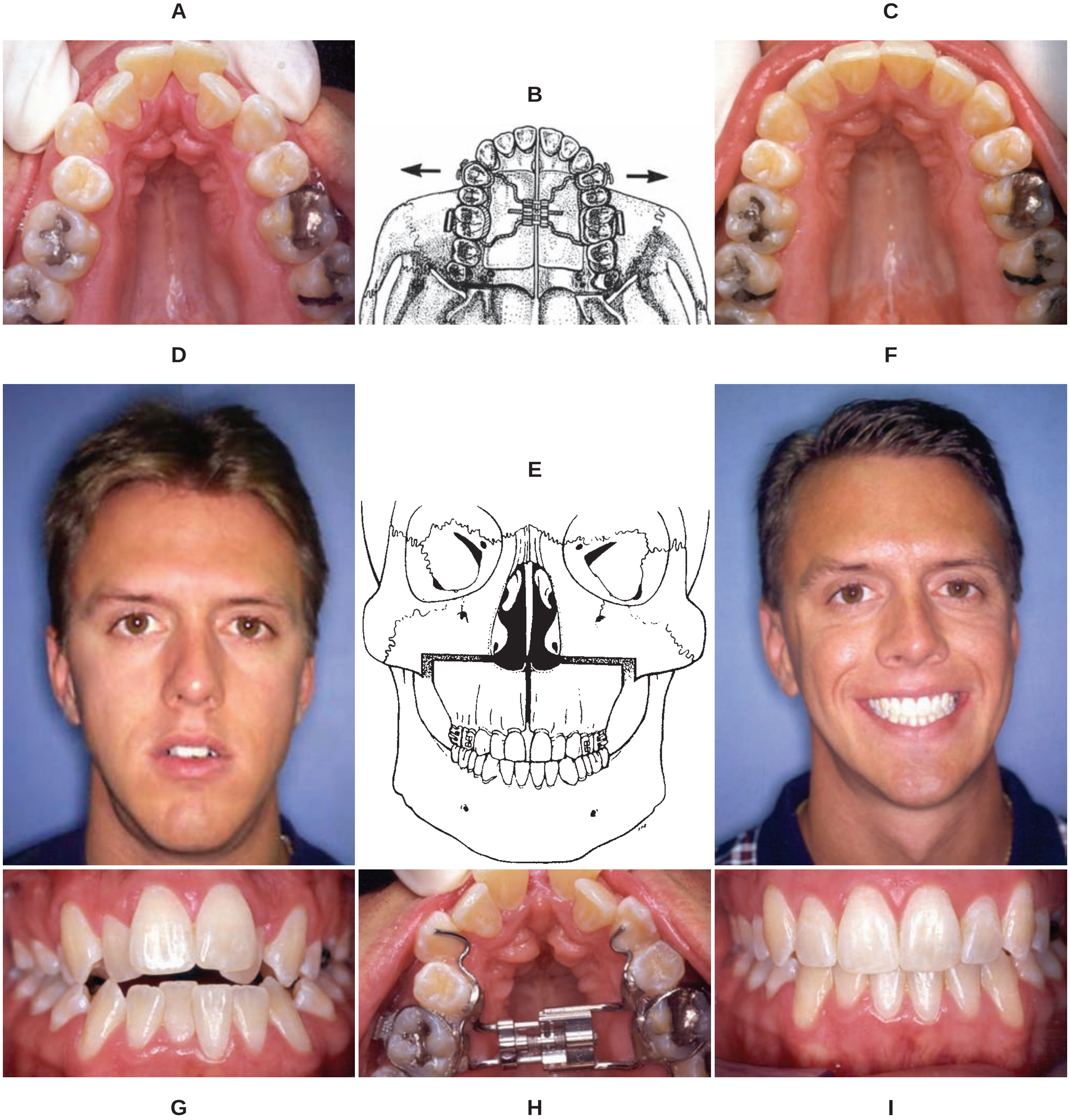


FIGURE 25-12 **A,** Presurgical frontal photograph of a patient showing a moderate degree of facial asymmetry. **B,** Frontal view of a differential Le Fort procedure of the maxilla and sagittal split rotation of the mandible and a differential genioplasty to resolve a facial asymmetry problem. **C,** Results after combination therapy. **D,** Presurgical smile showing vertical maxillary excess. **E,** Postsurgical smile showing improved aesthetics. *(Surgery by L. Lagrottia, Schaumburg, IL.)*



Treatment Milestones for Patients Requiring Surgically Assisted Rapid Palatal Expansion

Diagosis	Evaluation (1–4 Months)	Initial Treatment Steps (3 Months)	Orthodontic Correction (18–38 Months)	Stabilize (12–18 months)
With appropriate orthodontic study models and radiographs	By orthodontist and surgeon • Discuss procedure • Discuss risk/benefits • Evaluate insurance issues • Timing of procedures • Dental decompensation of lower arch • Preventative care of general dentist	1. Place expander (1 week prior to surgery)—Orthodontist 2. Outpatient surgery—Oral surgeon 3. At 5 days, initialize widening—Oral surgeon 4. Check in 1 week—Orthodontist 5. At approximately 14 days, place upper braces (RPE remains for 4–8 months)—Orthodontist	1. Level and align arches 2. Correct crowding/spacing 3. If needed, second phase jaw surgery for bite correction 4. Complete orthodontics	Orthodontist • Bonded maxillary and/or mandibular retainers • Removable maxillary retainer Reevaluate for restorative needs with general dentist

FIGURE 25-13 **A, D, G,** Problem: maxillary transverse deficiency before treatment. **B, E, H,** Schematic of surgical procedure: surgically assisted rapid maxillary expansion; a secondary surgical procedure (Le Fort osteotomy) was used to close the anterior open bite (shown in Figure 25-7, *B*). **C, F, I,** Orthodontic/surgical outcome: results after combination therapy. **J,** Milestones involved in a typical surgically assisted rapid palatal expansion treatment plan include the diagnosis using orthodontic study records; evaluation by the orthodontist and surgeon; initial treatment steps involving rapid palatal expansion surgery; orthodontic correction with full-bonded orthodontics; and stabilization with bonded and/or removable retainers. *(Surgery by M. Stohle, Glenview, IL.)*

counterclockwise direction to minimize the chance of postsurgical relapse. However, it has been shown that occlusal plane changes in the counterclockwise direction are indeed stable in long-term studies.[52,53] The use of this technique will allow for optimal function as well as profile enhancement with desirable lower third of face and chin repositioning. One of the more recent surgical technique modifications used by surgeons using the occlusal change approach to manage skeletal corrections is the design of the mandibular sagittal split (Figure 25-14).

Occlusal plane changes are stable in patients with normal TMJ function. However, it has been shown that patients with articular disc displacement who underwent counterclockwise movements exhibit more of a tendency to relapse in both the occlusal plane change area and horizontally at B point and menton.[54]

Another important surgical technique modification that has been presented in the literature recently is called *surgically facilitated orthodontic therap*y (SFOT).[55] This new technique, involving single or multiple tooth osteotomies combined with the principles of distraction osteogenesis to rapidly grow hard and soft tissues, allows changes in the alveolar position of the dentition (Figure 25-15). The SFOT concept builds upon the corticotomy technique that allows rapid tooth movement because of the bone demineralization caused by the regional acceleratory phenomenon. The technique can be considered for borderline surgical cases instead of orthognathic procedures, especially when a restorative component is required. It has the advantage of increasing the adult alveolar bone volume in both the anteroposterior and transverse direction. For the properly selected case, the economic advantage may be of great value with declining insurance coverage for certain orthognathic procedures. Case selection and outcomes can be seen in the treatments presented by Roblee et al.[55] Complications associated with the technique have been minor and uncommon but include gingival recession, devitalized teeth, and ankylosis of teeth.[56]

Skeletal Fixation

Immobilization of bone fracture sites is a necessity for proper healing of the bone. The acceptance of the technologic advances in orthognathic surgery by patients and the orthodontic profession has been influenced greatly by recent changes in fixation techniques. For many years interdental fixation with arch bars was the method of choice for orthognathic surgery patients. As presurgical orthodontic treatment became state of the art in the late 1960s, arch bars were replaced by interdental fixation with modified orthodontic appliances and by surgical arch wires with soldered hooks. Because of the limitations imposed by periodontally compromised teeth, short-rooted teeth, mutilated dentition, and double-jaw procedures, more stable forms of fixation using the skeletal bases were required.

Skeletal fixation used suspension wires from stable bone such as the infraorbital rim, the zygomatic arch, or the anterior nasal spine to the mobilized maxilla. The fixation period would last for at least 6 weeks. Postsurgical depression was common and the patient's interaction with the outside world was severely hampered. Weight loss, loss of appetite, TMJ pain, and facial muscle pain also became common concerns. Rigid fixation was introduced in 1980 in the oral and maxillofacial surgery literature. This technique helped eliminate one of the major hurdles for many patients considering jaw surgery, jaw immobilization. This obvious advantage allows (1) a normal ability to communicate, (2) a more normal diet, (3) less time away from work, (4) less sense of being handicapped or of feeling stigmatized, and (5) better oral hygiene during healing. Rigid fixation techniques use malleable plates, which are contoured to fit over a bony osteotomy and are fixated using screws. This holds the maxilla or mandible in this new position while healing.

Studies have shown that rigid fixation has acceptable, but variable relapse rates depending on the procedure.[57–63] Factors that affect stability in the mandible include magnitude of movement; proper seating of condyles, soft tissue, and muscles; the mandibular plane angle (a low angle has greater vertical relapse, a high angle has greater horizontal relapse); remaining growth; preoperative age; and hyperdivergent facial pattern.[64,65] Maxillary inferior positioning surgery is one of the more unstable orthognathic procedures.[66] Issues with rigid fixation include relapse, condylar resorption, and infection of plates or screws. Condylar position devices have been tried at length to help minimize relapse potential. There are many different devices and techniques available, but Gerressen et al. found their use did not lead to an increase in skeletal stability compared to the manual technique of seating the condyles in the fossa.[67] The benefits of rigid fixation include the previously mentioned patient issues as well as less pain as a result of less micromovement at

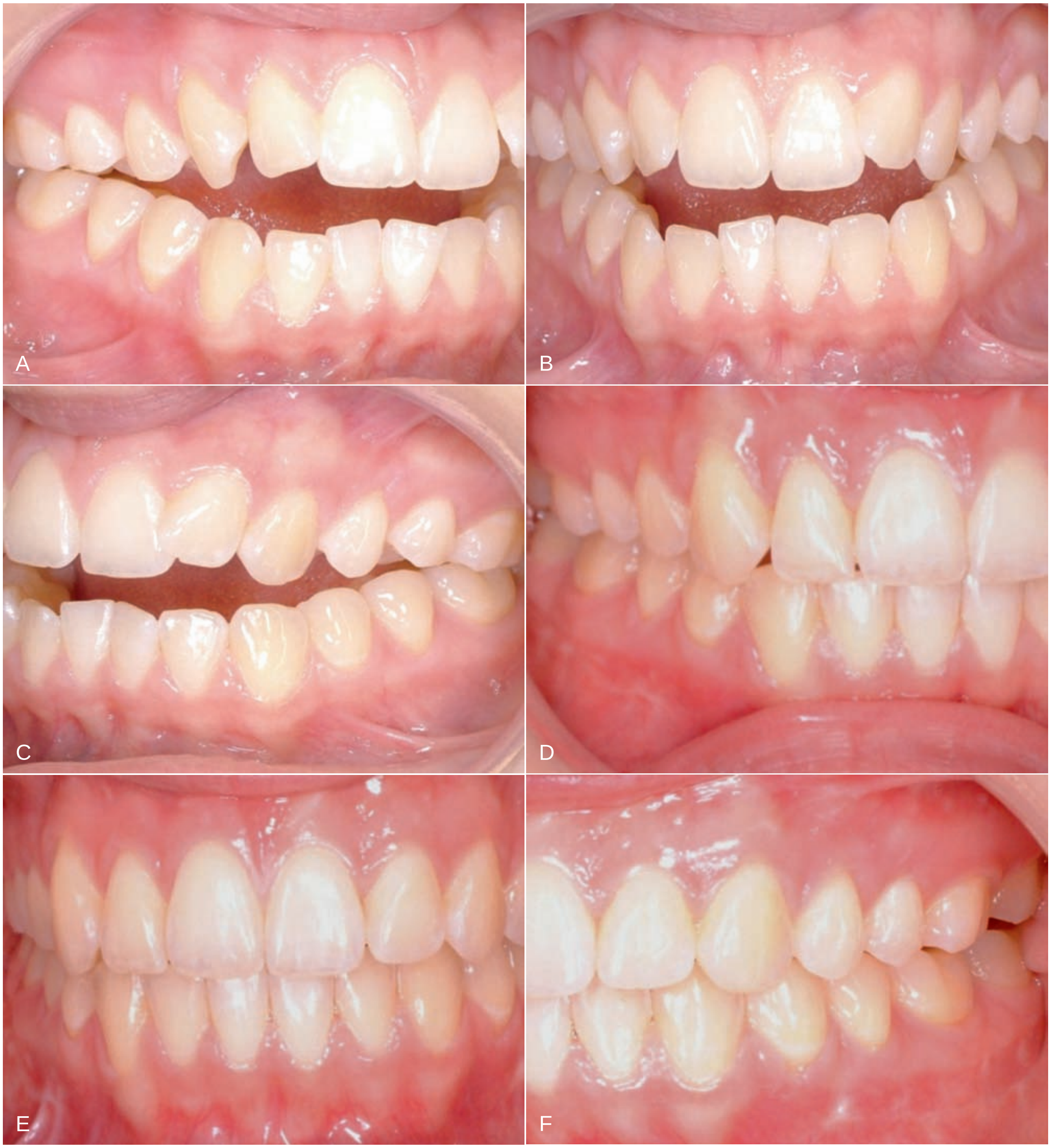


FIGURE 25-14 **A–C,** Intraoral photographs prior to any orthodontic treatment; note degree of anterior open bite and arch constriction. **D–F,** Intraoral photographs after orthodontic treatment and orthognathic surgery.

the osteotomy site afforded by rigid versus nonrigid fixation. There have been concerns that rigid fixation may increase the risk of temporomandibular disorders, but a study by Nemeth et al. showed no difference in the incidence of these disorders whether rigid or wire fixation was used.[68]

Some surgeons continue to use previously successful skeletal fixation in orthognathic surgery. Use of the rigid fixation technique will continue to be less than 100% until more long-term data are reported that clarify any possible latent negative effects for mandibular surgery. Examples of several fixation techniques are shown in the postsurgical cephalograms in Figure 25-16. The patient's choice obviously favors rigid fixation methods for all types of jaw surgery as long as stability and safety are not sacrificed.

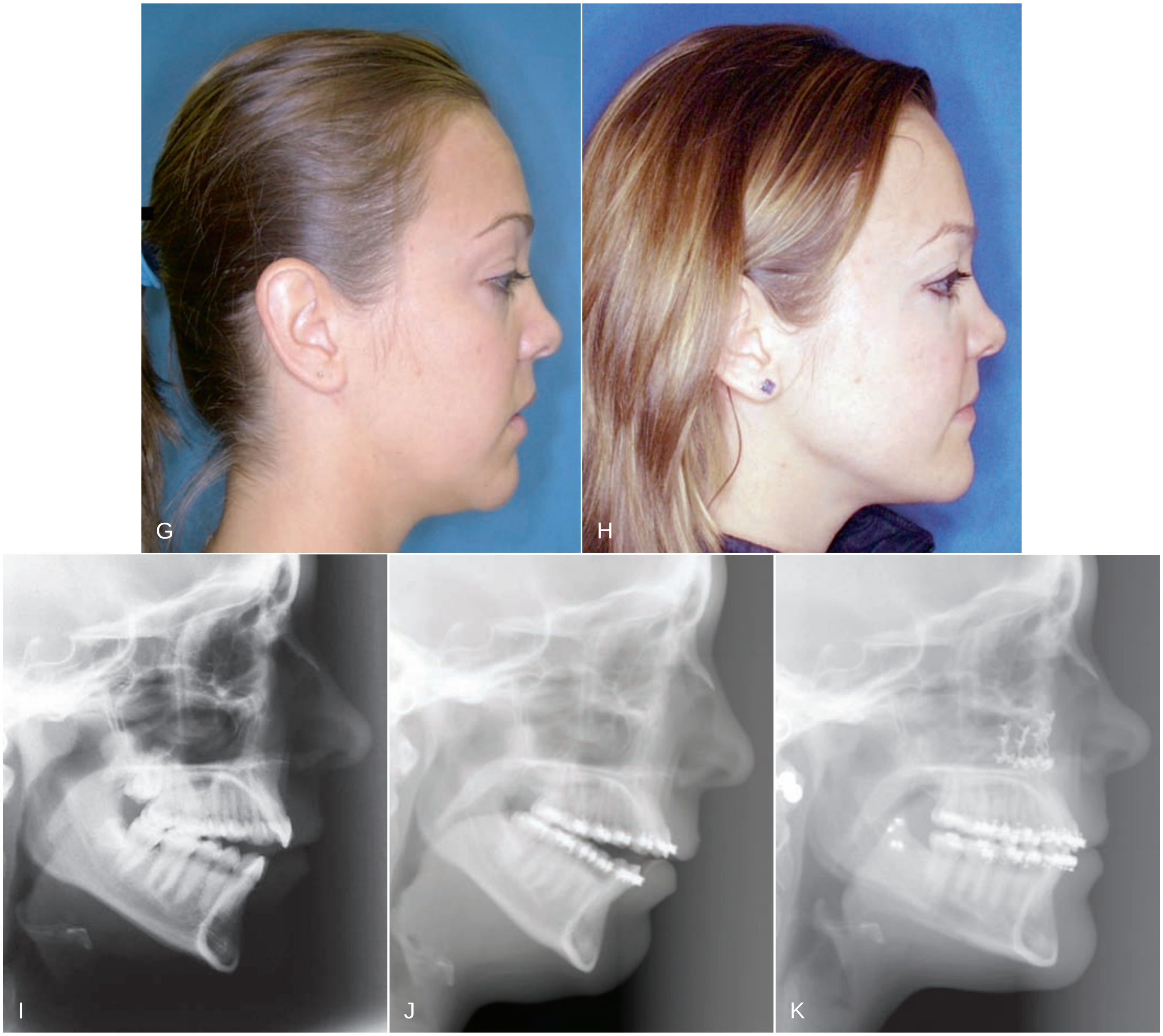


FIGURE 25-14, cont'd **G,** Profile prior to treatment. **H,** Profile after orthodontics and maxillo-mandibular surgery with *occlusal plane change* surgical modification. **I–K,** Cephalograms: pretreatment, pre-surgical after orthodontic preparation, and post-surgical, respectively. Post-surgical **(K)** shows significant amount of mandibular rotation and occlusal plane change to close bite and to optimize facial balance.

The rate at which chewing capacity, range of motion, and functional comfort return are affected greatly by the type of surgery, the type of fixation, and the quality of postoperative management. Studies have shown that functional improvement occurs faster if physical therapy is added to the postsurgical regimen.[69] Figure 25-17 presents the basic flowchart for jaw rehabilitation used by the surgical team at the University of North Carolina School of Dental and Hospital Medicine.[70]

Figures 25-4 to 25-13 show schematic illustrations of some of the more common surgical procedures currently used to correct skeletal malocclusions. Figure 25-14 illustrates the positive effect of including the "occlusal plane change" technique to the orthognathic procedure.

PATIENT TREATMENT

See Box 25-3.

Diagnostic Considerations

Cone-beam computed tomography (CT) has become increasingly available and gives a three-dimensional view of the patient's facial structure.[71–79] Information gained is used for treatment planning and gaining a

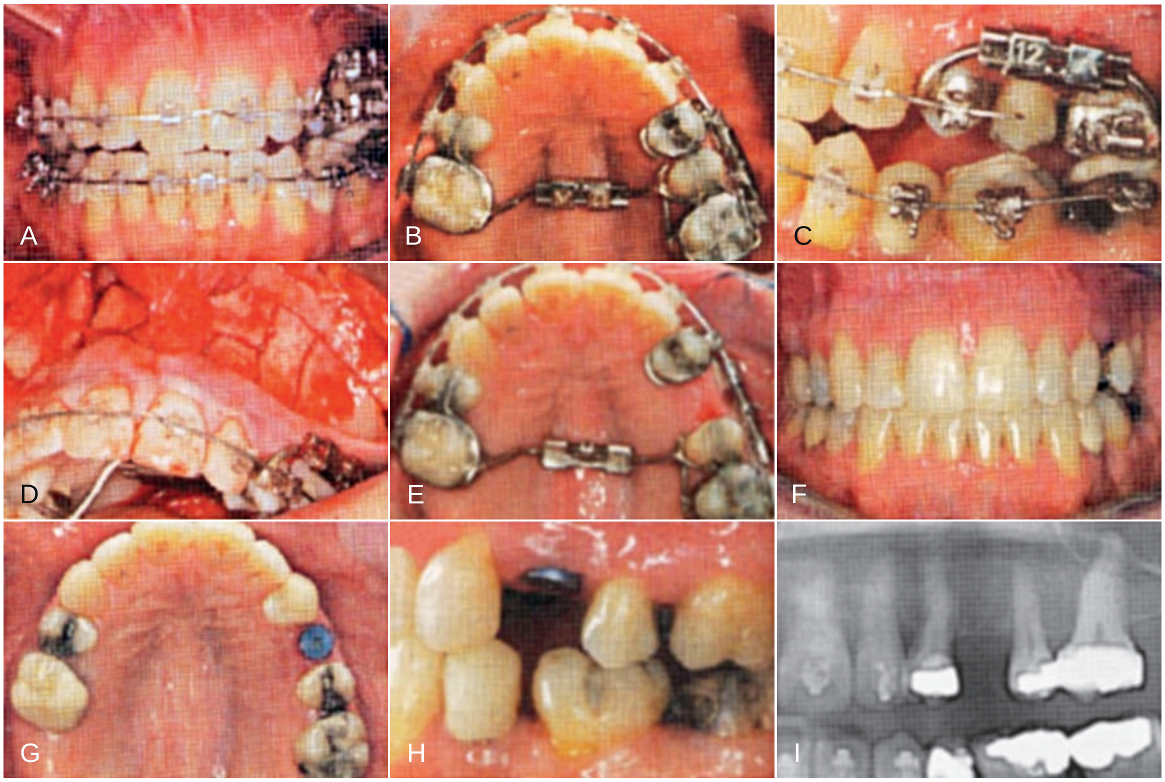


FIGURE 25-15 **A–C,** An osteotomy in surgically facilitated orthodontic treatment (SFOT) consists of cuts through both the cortical and medullary bone and typically indicates the creation of one or more dento-osseous segments. Shown here is a 50-year-old female concerned about appearance and bite. Jackscrew appliance was placed after 6 months of orthdontic alignment. **D–F,** Patient was missing No. 11 and had A-P and transverse maxillary deficiencies with anterior and left posterior cross-bites. The bite was opened with glass ionomer cement. Single-tooth osteotomies were performed on Nos. 6 to 12 and multiple osteotomies were completed on Nos. 3 to 4, 7 to 10 and 13 to 14. **G,** Corticotomies were also performed on Nos. 7 to 10 segment. **H,** Jackscrews were activated 0.5 mm/day after 5-day latency period. Note pure translation of segments without tipping. Result of 8 months postsurgery. **I,** Tooth No. 12 was converted to a canine, and an implant was placed in regenerate bone. Note amount of alveoloskeletal correction and increase in volume of maxillary arch.

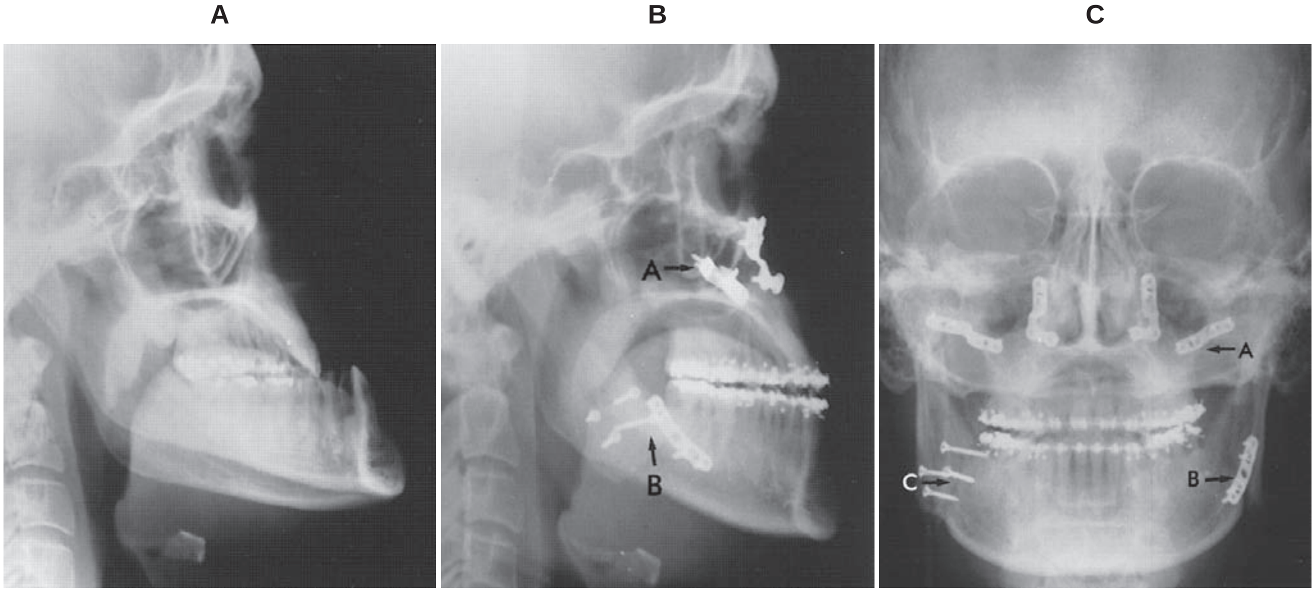


FIGURE 25-16 **A,** Pretreatment lateral cephalogram of a patient (33 years 10 months) with a severe maxillary deficiency and mandibular excess. **B,** Postsurgical lateral cephalogram showing advancement of the maxilla and mandibular setback. *Arrow A*: Rigid fixation plates stabilizing the maxillary Le Fort advancement; *arrow B*: rigid fixation screws and plate stabilizing the sagittal split mandibular setback. **C,** Postsurgical frontal cephalogram. *Arrow A*: Maxillary fixation plates; *arrow B*: mandibular fixation screws; *arrow C*: mandibular fixation plate. This patient delayed surgery for 9 years to avoid 8 weeks of intermaxillary fixation and the downtime from work. Five days after his double-jaw surgery, he returned to work. Stabilization was with rigid fixation devices only.

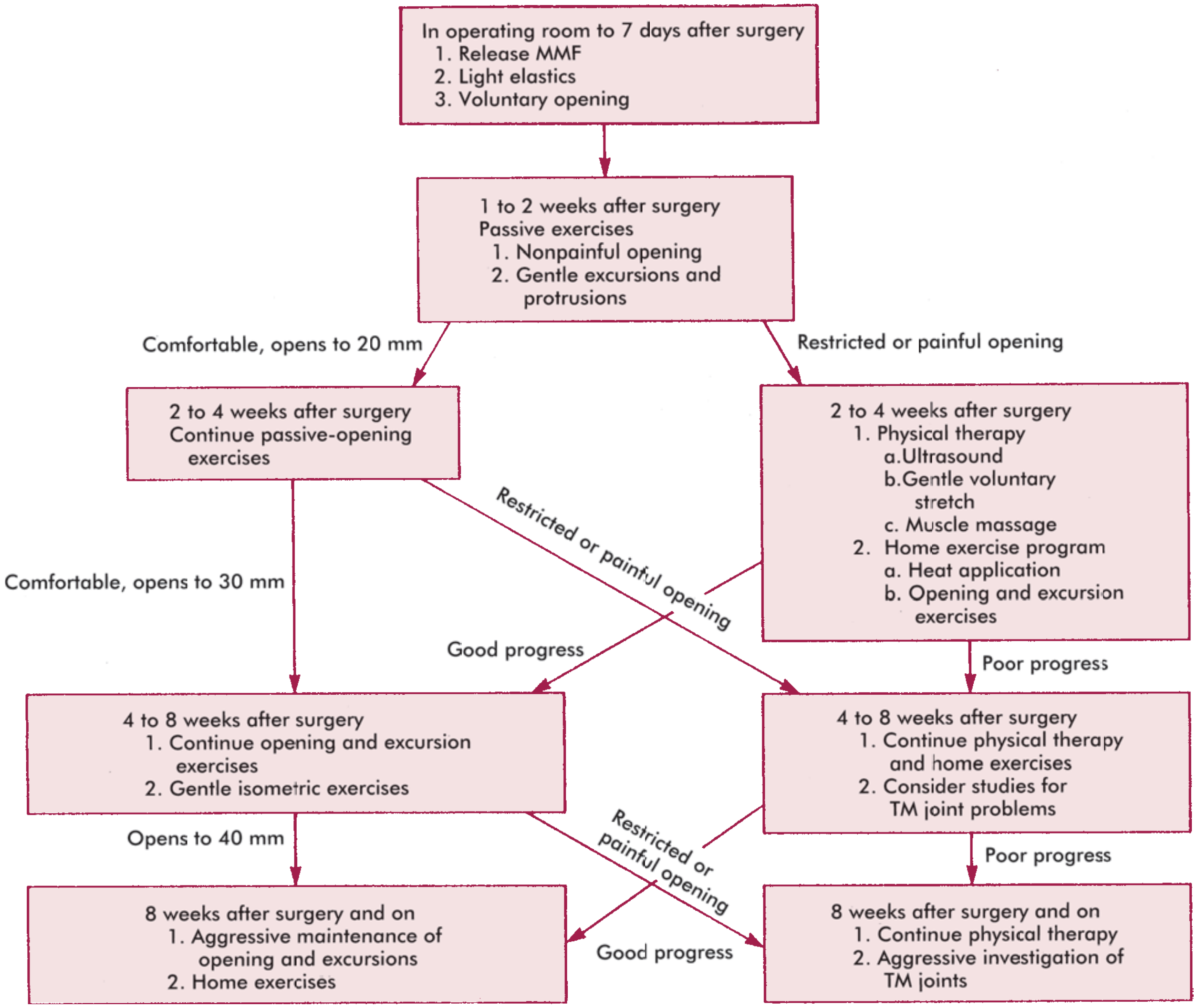

In operating room to 7 days after surgery
1. Release MMF
2. Light elastics
3. Voluntary opening
1 to 2 weeks after surgery
Passive exercises
1. Nonpainful opening
2. Gentle excursions and protrusions
Comfortable, opens to 20 mm
Restricted or painful opening
2 to 4 weeks after surgery
Continue passive-opening exercises
2 to 4 weeks after surgery
1. Physical therapy
a. Ultrasound
b. Gentle voluntary stretch
c. Muscle massage
2. Home exercise program
a. Heat application
b. Opening and excursion exercises
Restricted or painful opening
Comfortable, opens to 30 mm
Good progress
Poor progress
4 to 8 weeks after surgery
1. Continue opening and excursion exercises
2. Gentle isometric exercises
4 to 8 weeks after surgery
1. Continue physical therapy and home exercises
2. Consider studies for TM joint problems
Opens to 40 mm
Restricted or painful opening
Poor progress
Good progress
8 weeks after surgery and on
1. Aggressive maintenance of opening and excursions
2. Home exercises
8 weeks after surgery and on
1. Continue physical therapy
2. Aggressive investigation of TM joints

FIGURE 25-17 Flowchart for jaw rehabilitation. *MMF*, Maxillomandibular fixation; *TM*, temporomandibular.

BOX 25-3 Characteristics of Adult Patients Seeking Orthodontic Retreatment

A. Distribution of orthodontic conditions identified in study of 100 patients seeking retreatment (most serious problem prioritized in tabulations)
   1. Skeletal problems (42%): Class II, open bites, Class III, and transverse maxillary deficiency
   2. Lower incisor (25%): unacceptable alignment
   3. Upper incisors (21%): unacceptable alignment
      - Central incisor problems
      - Lateral incisor problems
   4. Other (12%): temporomandibular joint, trauma, and periodontal issues

B. Distribution of skeletal problems identified in study of 100 patients seeking retreatment
   - Class II, high angle: 20
   - Class II, medium angle: 3
   - Class III, several types: 15
   - Class I, high angle: 3
   - Class I, maxillary transverse deficiency: 1

C. Case characteristics of skeletal patients from retreatment study
   - Age (range): 15 to 59 years
   - Age (mean): 30.12 years
   - Number of males: 13 (31%)
   - Number of females: 29 (69%)

D. Acceptance rate of skeletal cases identified in retreatment study
   - Accept braces and surgical plan: 29 of 42 (69%)
   - Accept orthodontics only; leave bite uncorrected: 4 of 42 (10%)
   - Did not accept additional treatment: 9 of 42 (21%)

better preoperative understanding of a jaw deformity in all three planes of space. Cephalometric analyses are being developed to bring information to the operating room (Figure 25-18).[75] Surgical splints can be prefabricated based on data from the CT scan after the maxilla and/or mandible has been virtually moved.[76,78] Stereolithographic models based on scans can help increase intraoperative accuracy.[77] This tool is extremely useful in fully uncovering a patient's deformity so that proper planning will occur to produce an optimal result (Figures 25-19 and 25-20).

For most patients, orthodontic treatment decisions have a significant elective component. Although the patient is examined for any pathologic conditions and medical problems, the orthodontist generally focuses on diagnostic considerations of the structural imbalances (Table 25-4). Three fundamental factors in the diagnostic process are (1) the standardization of high-quality records, (2) consistency of record analysis, and (3) clarity and integration of diagnostic thought by the members of the orthognathic team.

Franchi, Baccetti, and McNamara indicated that cephalometric "floating norms" be considered in understanding the diagnosis of skeletal imbalances: "The use of cephalometric floating norms may be helpful for diagnosis and treatment planning in orthognathic surgery and dentofacial orthopedics."[80] Cephalometric analyses using a template method (Jacobson)[81] are able graphically to qualify (demonstrate which jaw is not in balance) and quantify (demonstrate the degree to which each jaw's dental and skeletal components contribute to the imbalance).

Superimposition of the Broadbent/Bolton template, similar in concept to the Jacobson approach, has proved

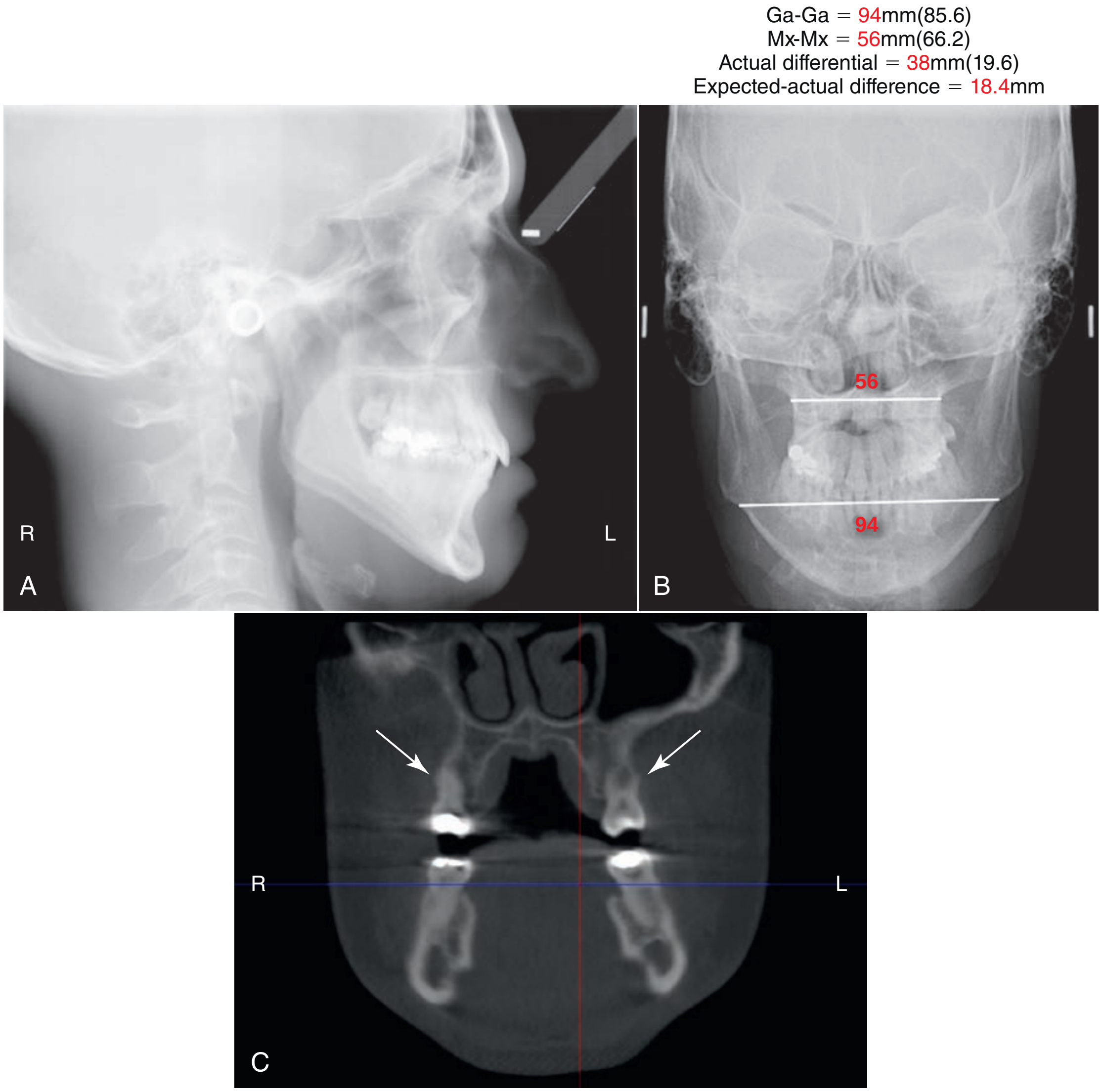

Ga-Ga = 94mm(85.6)
Mx-Mx = 56mm(66.2)
Actual differential = 38mm(19.6)
Expected-actual difference = 18.4mm
R
L
A
56
94
B
R
L
C

FIGURE 25-18 Digital frontal cephalogram. As cone beam technology advances our capacity to identify and measure anatomic landmarks, more accurate diagnosis of maxillary skeletal transverse deficiency will be a clear part of the orthodontic diagnostic protocol.

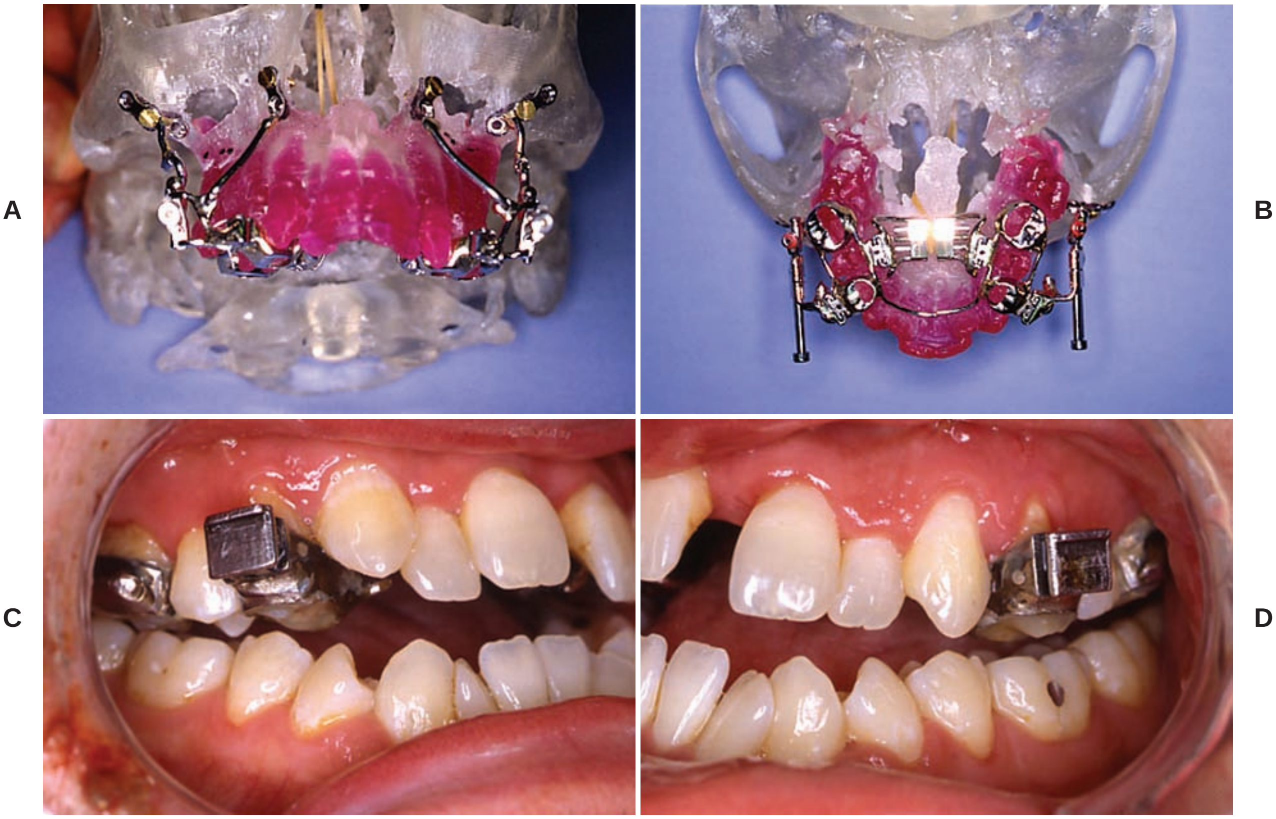


FIGURE 25-19 **A, B,** Stereolythic plastic model of patient's maxillary anatomy used to create custom two-dimensional distraction appliance (transverse expander and anteroposterior advancement). **C, D,** Intraoral view of appliance after 2 weeks of "distraction activation."

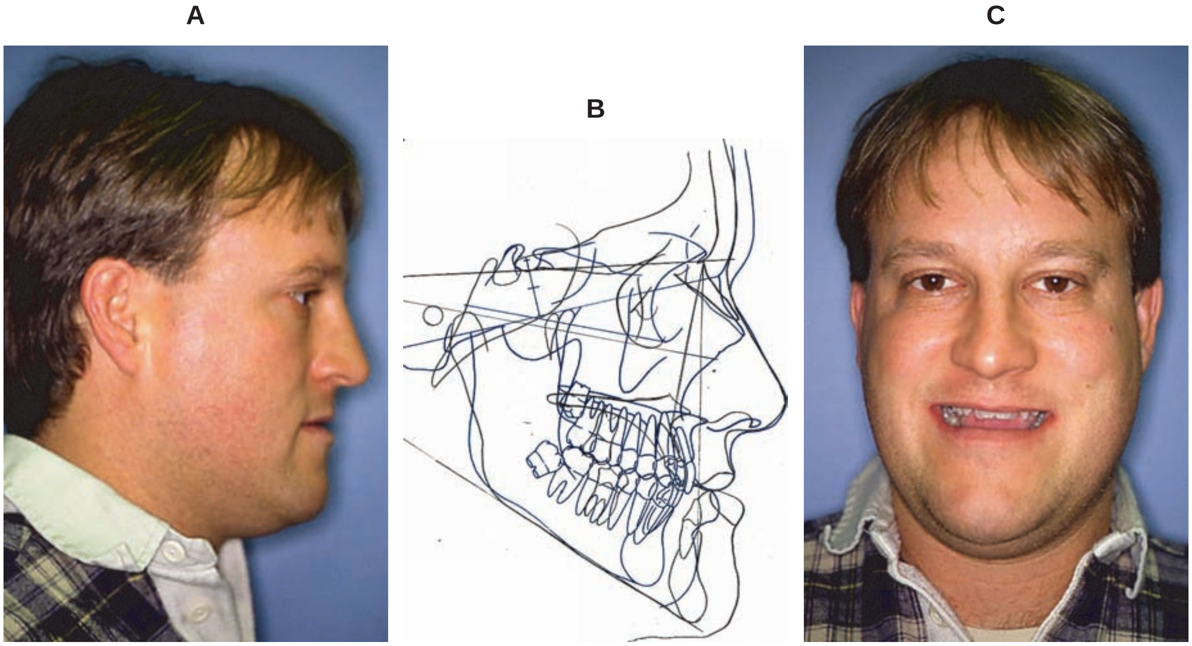


FIGURE 25-20 **A,** Pretreatment profile photograph. **B,** Patient tracing with Bolton template used to guide direction and amount of skeletal and dental changes needed for correction. **C,** Pretreatment facial photograph.

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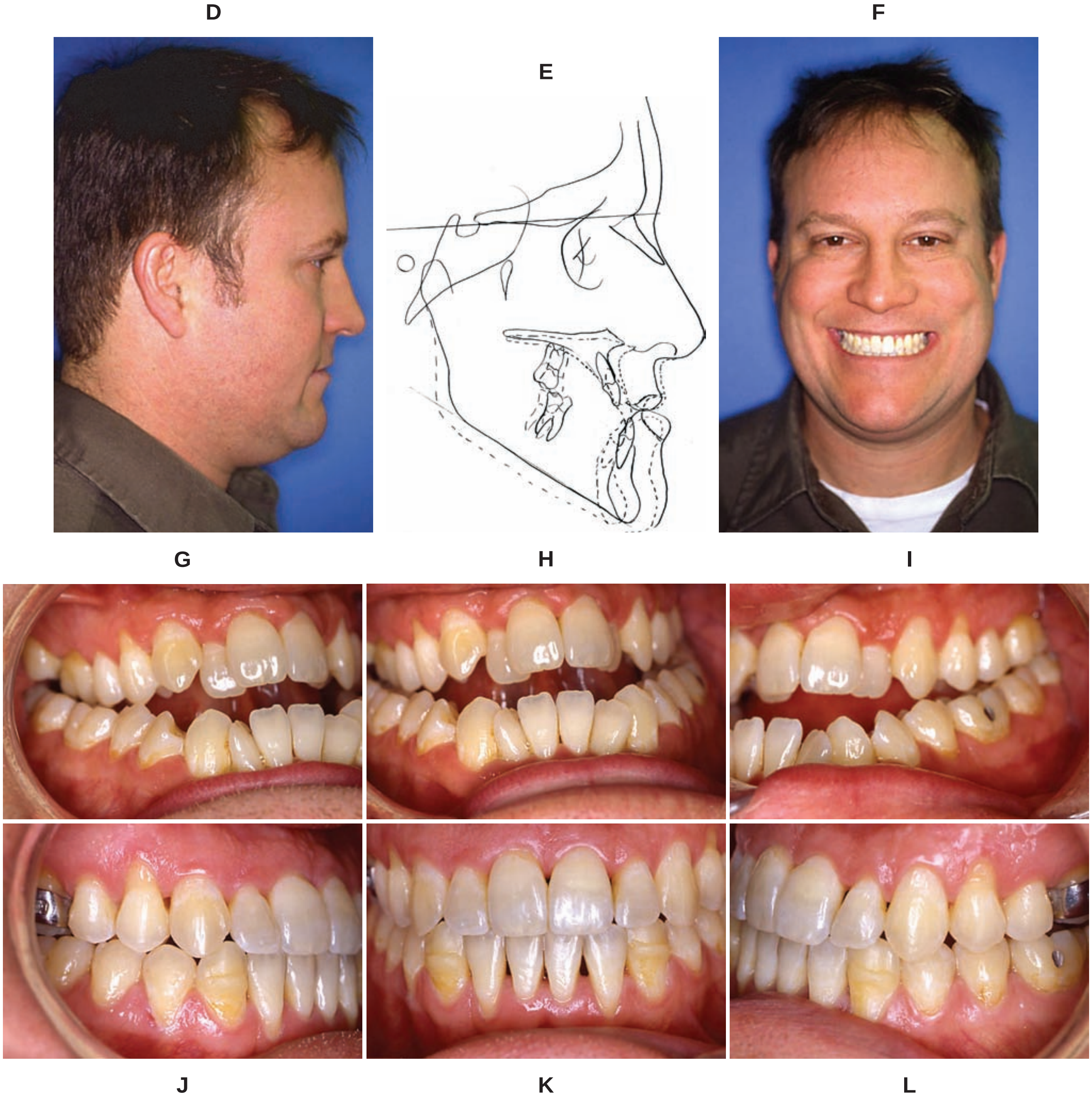

FIGURE 25-20, cont'd **D,** Posttreatment profile photograph. **E,** Superimposition of lateral cephalogram tracing (*solid lines* represent pretreatment appearance; *dashed lines* represent posttreatment appearance). **F,** Posttreatment facial photograph. **G–I,** Pretreatment intraoral photographs showing severe skeletal Class III malocclusion, crowding, anterior and posterior crossbites, and anterior open bite. **J–L,** Posttreatment intraoral photographs showing Class III correction after (*1*) phase I distraction surgery to resolve maxillary transverse deficiency and to reduce anteroposterior maxillary deficiency, (*2*) orthodontic treatment for about 22 months to decompensate dental malpositions, and (*3*) phase II jaw surgery to advance maxilla to complete the anteroposterior correction and to set mandible back and correct mandibular asymmetry and excess.

TABLE 25-4 Medical Problems Significant for Surgical-Orthodontic Treatment*

Condition	Significance	Comments
Diabetes mellitus	Susceptible to periodontal breakdown during orthodontic treatment; decreased resistance to infection; poor wound healing	Maintenance of excellent control is necessary.
Hyperthyroidism	Increased metabolic rate; tendency to osteoporosis	Infection may create crisis; psychological instability is possible.
Adrenal insufficiency	Decreased stress tolerance; delayed healing	Knowledge of steroid dosage is important.
Pregnancy	Major hormonal changes; increased susceptibility to periodontal breakdown	Defer surgical treatment; limited orthodontic treatment is acceptable, but careful periodontal monitoring is required.
Rheumatic heart disease, other heart disease	Susceptible to endocarditis	Antibiotic coverage is required for invasive procedures (in orthodontics, for banding but not for bonding or routine adjustments).
Bleeding disorders (e.g., hemophilia, von Willebrand disease, and thrombocytopenia)	Susceptible to bleeding	Replace missing clotting factors before surgery (in orthodontics, bonded attachments instead of bands and avoidance of aspirin and related drugs for pain control).[106]
Sickle cell anemia	Susceptible to sickle cell crisis and bone loss	Patients are not good candidates for general anesthesia; therefore they usually are not considered for orthognathic surgery.
Allergy-immune problems	Excessive reaction to drugs and other antigens	In rare cases, nickel content in stainless steel orthodontic appliances causes problem.
Rheumatoid arthritis	Episodic involvement of multiple joints and possible destruction of temporomandibular joint (TMJ)	Manipulation of TMJ tends to exacerbate problem; avoid functional appliances, Class II elastics, and mandibular advancement.
Osteoarthritis	Progressive involvement of multiple joints, possibly including TMJ, with increasing age	Orthodontics or orthognathic surgery has little effect for better or worse on involved TMJ.
Behavioral disorders	Depends on degree of control; patients often taking potent medications	Drug effects may slow orthodontic tooth movement; bizarre reactions to surgery are possible.

Adapted from Proffit WR, White RP: *Surgical-orthodontic treatment*, St Louis, 1990, Mosby.

*In all instances, surgical-orthodontic treatment should be undertaken only after these and related conditions are under medical control.

to be a simple, quick, and reliable tool that could be used in consultation with the treating oral surgeon and with patients to demonstrate the direction and approximate amount of surgery needed to correct the skeletal disharmony (Figures 25-21 to 25-27). Proffit has discussed the use of template analysis in the surgical textbook he wrote with White.[37] Proffit pointed out that the template may appear to be less scientific than a table of cephalometric measurements with standard deviations, but he also noted that "the template is a visual analog of a table and is just as valid." Proffit also explains, "What the template does is place the emphasis on the analysis itself; that is, deciding what the distortions are, rather than on an intermediate measurement step that too often becomes an end in itself rather than just a means to an end."

The authors have found that the template approach to cephalometric analysis allows an assessment of skeletal landmarks compared with age-matched norms. Use of nasal superimposition fully integrates the nose into cephalometric assessment and allows the clinician to assess soft tissue compensation for skeletal imbalance. The authors have found this approach to be excellent for diagnosis and treatment planning for skeletal dysplasias. In its application, it should be considered *template-guided diagnosis and treatment planning* and is illustrated in Figures 25-21 to 25-27.

In addition to diagnosing the anteroposterior and vertical skeletal components of the patient's disharmony, it is essential to also make an accurate diagnosis of the contributing transverse skeletal component. Until three-dimensional diagnostic parameters are clearly established (see Chapter 4), the analysis of frontal radiographs continues to be an effective approach to identify true transverse skeletal discrepancies that may require surgical management (Figure 25-28).

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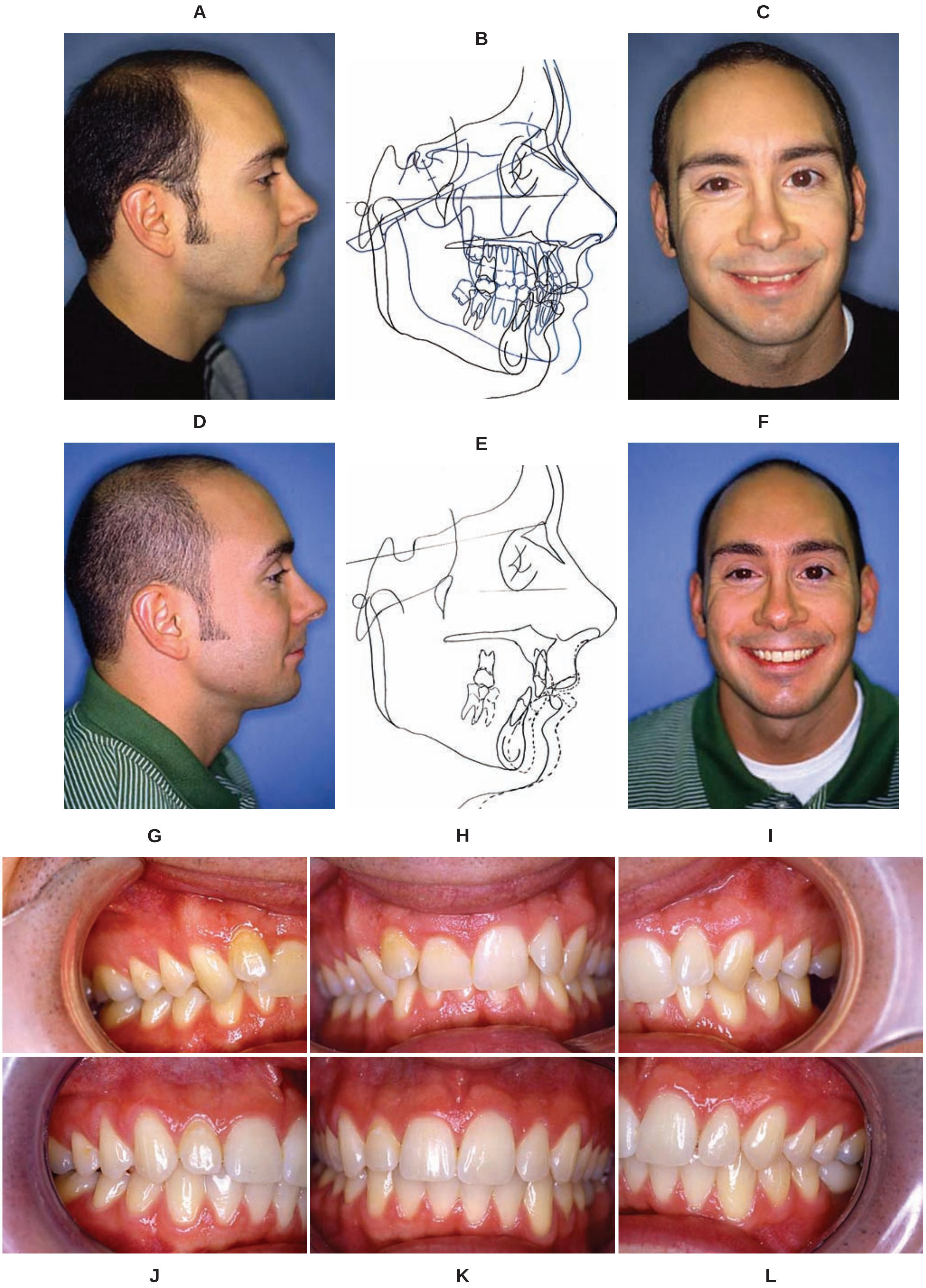
A
B
C
D
E
F
G
H
I
J
K
L

FIGURE 25-21 Patient: TH, 27 years 10 months, male

Classification: Class II, Division 2, deep bite, and bite collapse on left

Qualification: Mandibular anteroposterior deficiency and vertical deficiency

Quantification: 100% mandibular skeletal deficiency; mandibular vertical deficiency; moderate horizontal excess in chin area camouflages the skeletal deficiency of the mandible

Severity: 8 of 10 with 10 being most severe and 0 being perfect.

Prognosis: 1 of 10 with comprehensive orthodontics and jaw surgery.

A, Pretreatment profile photograph. **B,** Bolton template-guided diagnosis and treatment plan. **C,** Pretreatment facial photograph. **D,** Posttreatment profile photograph. **E,** Cephalometric superimposition. **F,** Posttreatment smile photograph. **G–I,** Intraoral pretreatment photographs showing Class II malocclusion. **J–L,** Intraoral posttreatment photographs showing optimal correction with replacement of missing No. 19.

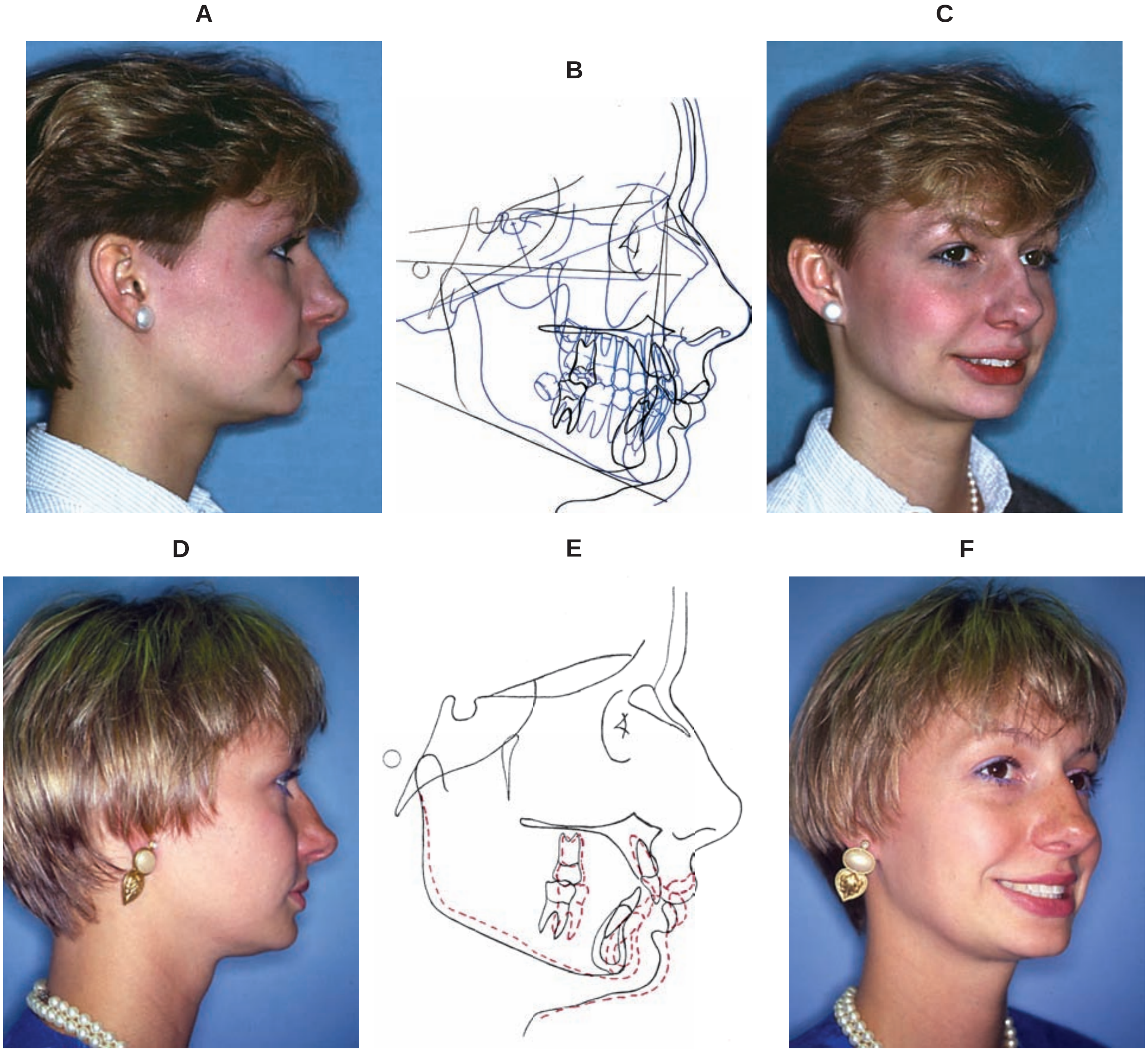

FIGURE 25-22 Patient: JT, 17 years 11 months, female

Classification: Class II, Division 1

Qualification: Mandibular deficiency type II

Quantification: 100% mandibular deficiency with normal maxillary skeletal and dental position as seen through template analysis (14C)

Severity: 7 of 10

Prognosis: 0.5 of 10 with comprehensive orthodontics and jaw surgery

A, Pretreatment profile photograph showing evidence of mandibular deficiency. **B,** Bolton template-guided diagnosis and treatment plan used template superimposition that shows good maxilla position and horizontal and vertical mandibular deficiency. **C,** Pretreatment facial photograph. **D,** Posttreatment profile photograph showing change as a result of orthodontic treatment and mandibular advancement. **E,** Cephalometric superimposition showing corrected mandibular deficiency. **F,** Posttreatment smile photograph.

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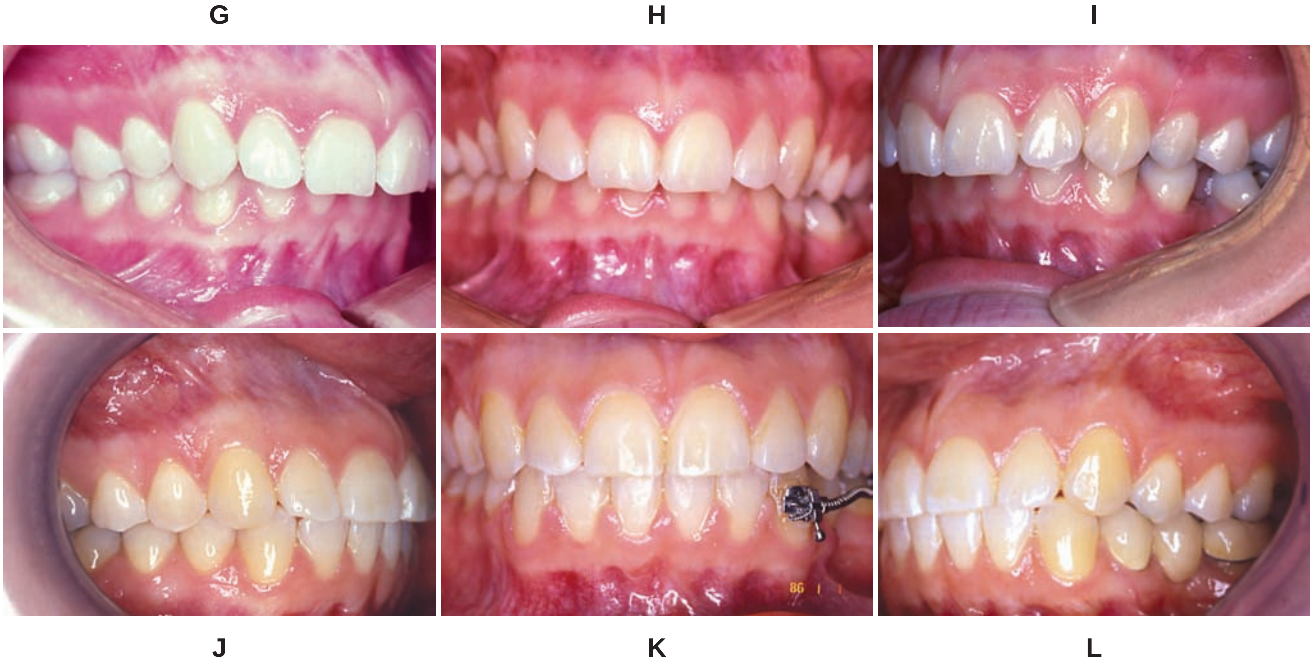

FIGURE 25-22, cont'd **G–I,** Intraoral pretreatment photographs showing Class II malocclusion, bite collapse, and deep bite. **J–L,** Intraoral posttreatment photographs showing correction with bridge in **L** replacing No. 19.

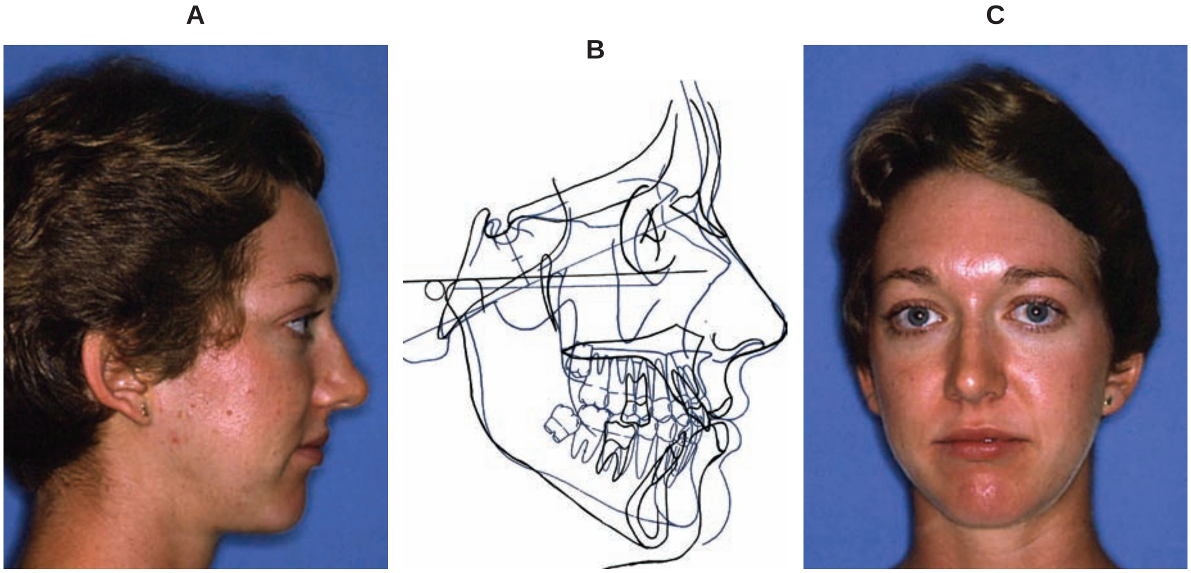

FIGURE 25-23 Patient: LG, 26 years 4 months, female

Classification: Class II, Division 1

Qualification: Mandibular deficiency type III with open bite

Quantification: Maxillary posterior vertical excess in 100% mandibular deficiency

Severity: 8 of 10 (patient also has temporomandibular joint pain and disk displacement with reduction)

Prognosis: Temporomandibular (reevaluate) occlusal function 1 of 10; favorable prognosis with comprehensive orthodontic treatment and jaw surgery

A, Pretreatment profile photograph. **B,** Bolton template-guided diagnosis and treatment plan. **C,** Pretreatment facial photograph.

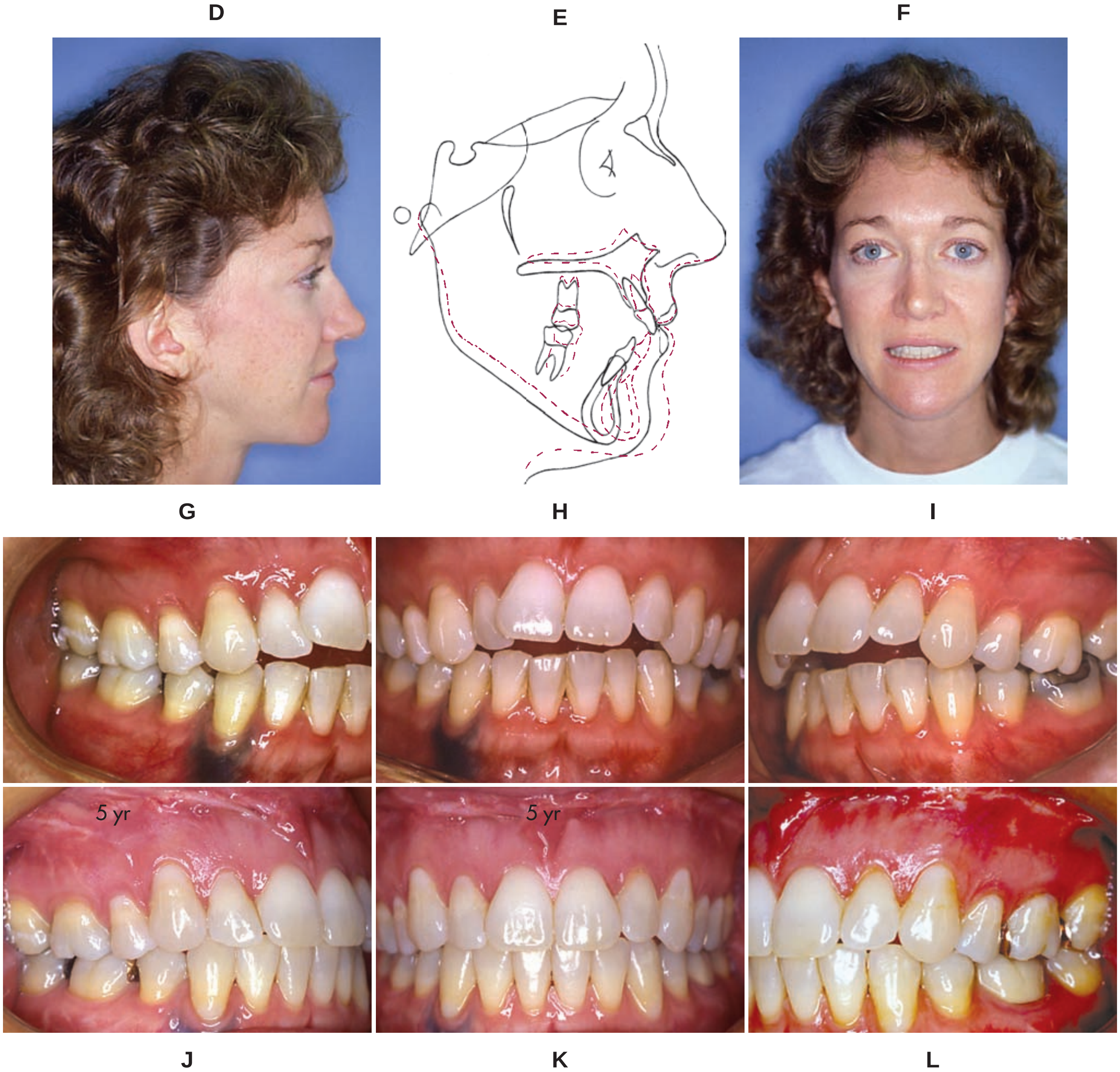

FIGURE 25-23, cont'd **D,** Posttreatment profile photograph. **E,** Cephalometric superimposition. **F,** Posttreatment smile photograph. **G–I,** Intraoral pretreatment photographs showing malocclusion. **J–L,** Intraoral posttreatment photographs showing optimal correction.

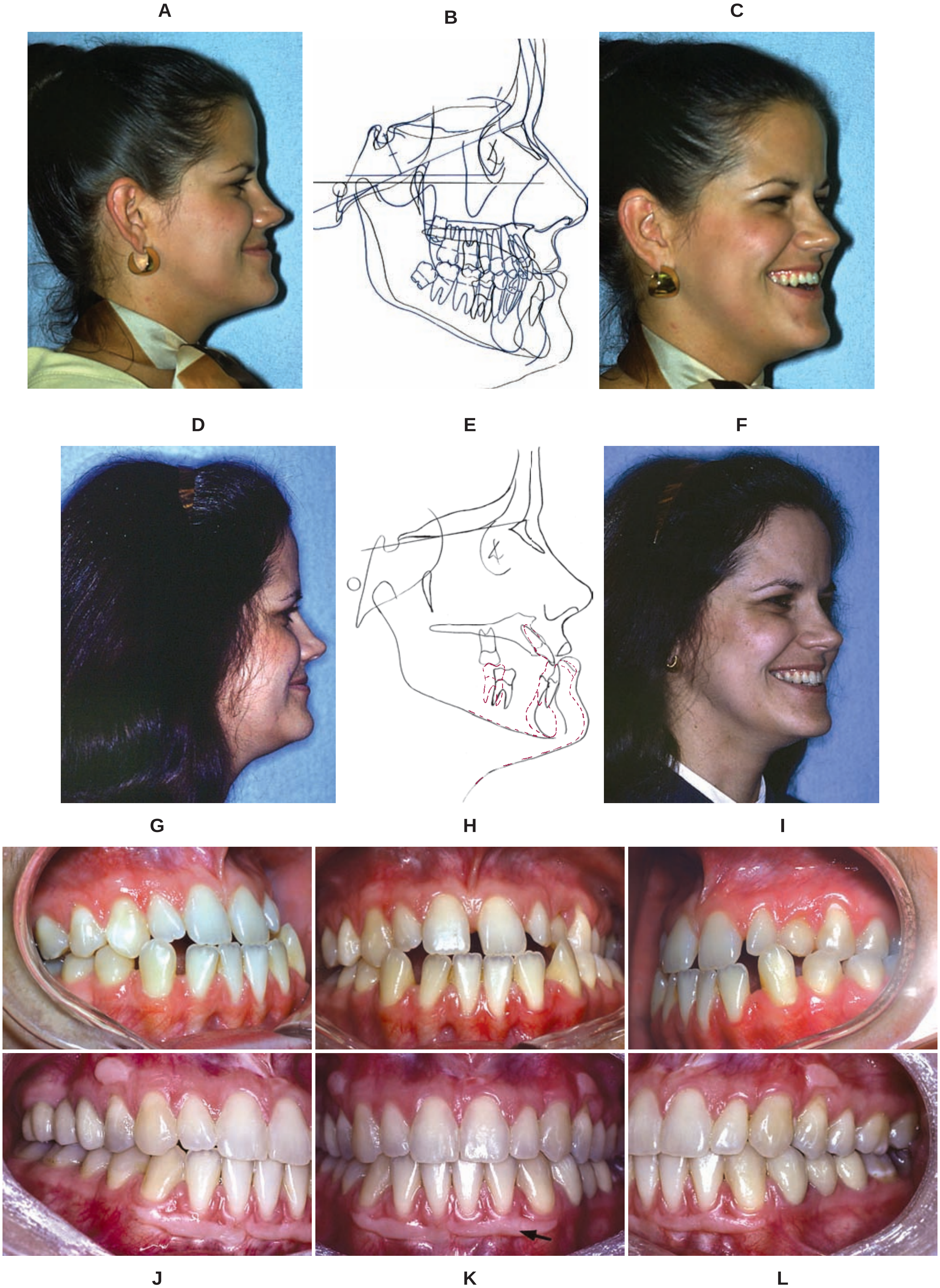
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FIGURE 25-24 Patient: PM, 24 years 3 months, female

Classification: Class III mandibular excess type I (low mandibular plane angle)

Qualification: Mandibular skeletal excess with significant maxillary dentoalveolar compensation and relative protrusion

Quantification: 100% mandibular excess

Severity: 8.5 of 10; severe skeletal problem; impaction of No. 11, dental spacing, and mucogingival deficiency

Prognosis: 2 of 10; prognosis is estimated at 2 because of the impacted canine and other dental problems that require management; patient has a good attitude for handling complicating factors in treatment

A, Pretreatment profile photograph. **B,** Bolton template-guided diagnosis and treatment plan. **C,** Pretreatment facial photograph. **D,** Posttreatment profile photograph. **E,** Cephalometric superimposition. **F,** Posttreatment smile photograph. **G–I,** Intraoral pretreatment photographs showing malocclusion. **J–L,** Intraoral posttreatment photographs showing optimal correction. Note an extra premolar was added between No. 20 and No. 21 to aid in dental decompensation and to stabilize excess lower spacing.

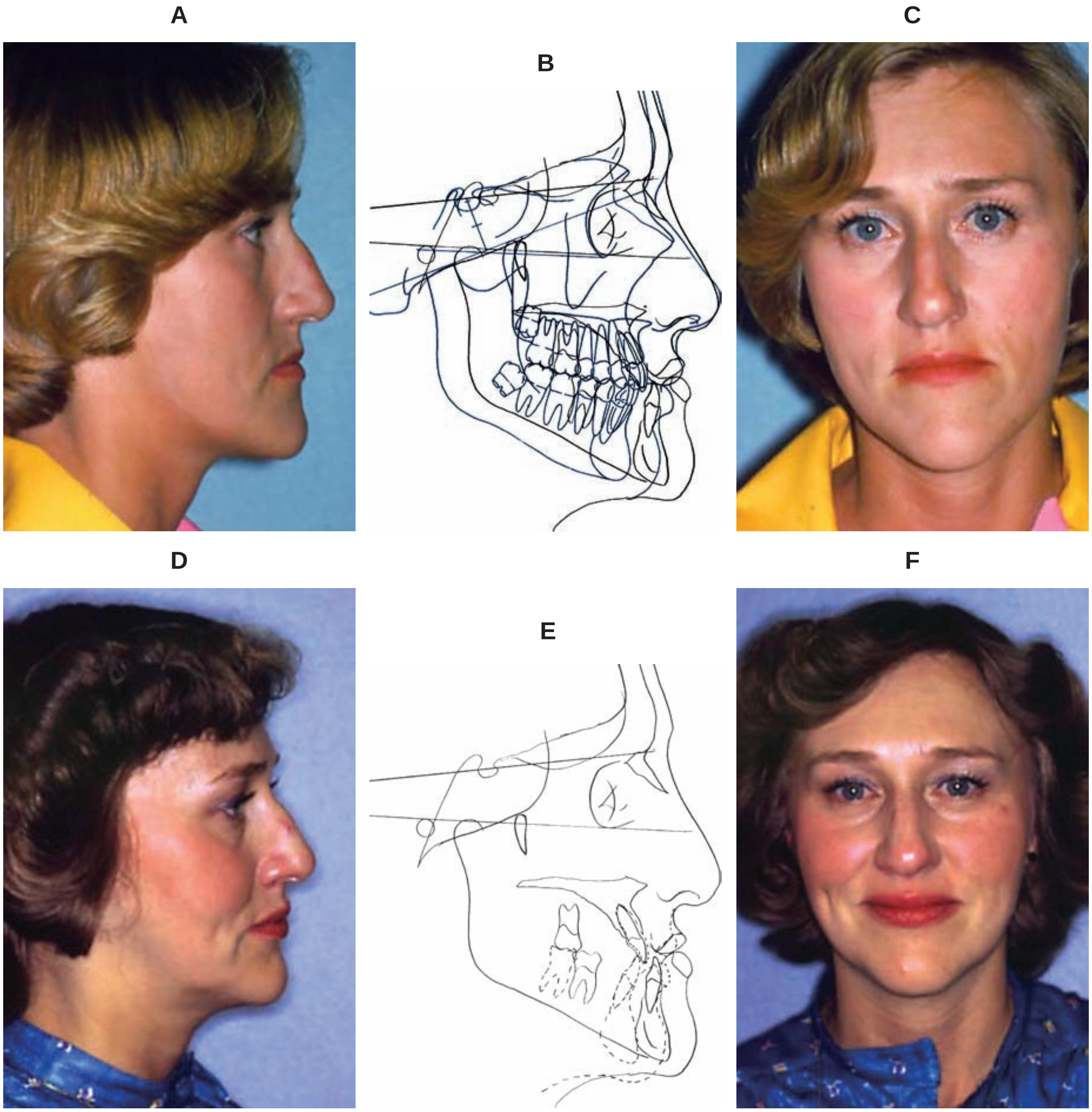

FIGURE 25-25 Patient: EF, 30 years 8 months, female

Classification: Class III skeletal condition

Qualification: Mandibular excess type II (moderate mandibular plane angle)

Quantification: 100% mandibular excess

Severity: 7 of 10 skeletal severity and long-standing dental compensation of the lower incisors

Prognosis: 2 of 10; the prognosis is good with full orthodontic treatment and jaw surgery (chin excess and nasal form may require cosmetic procedure for ideal outcome)

A, Pretreatment profile photograph. **B,** Bolton template-guided diagnosis and treatment plan. **C,** Pretreatment facial photograph. **D,** Posttreatment profile photograph. **E,** Cephalometric superimposition. **F,** Posttreatment smile photograph.

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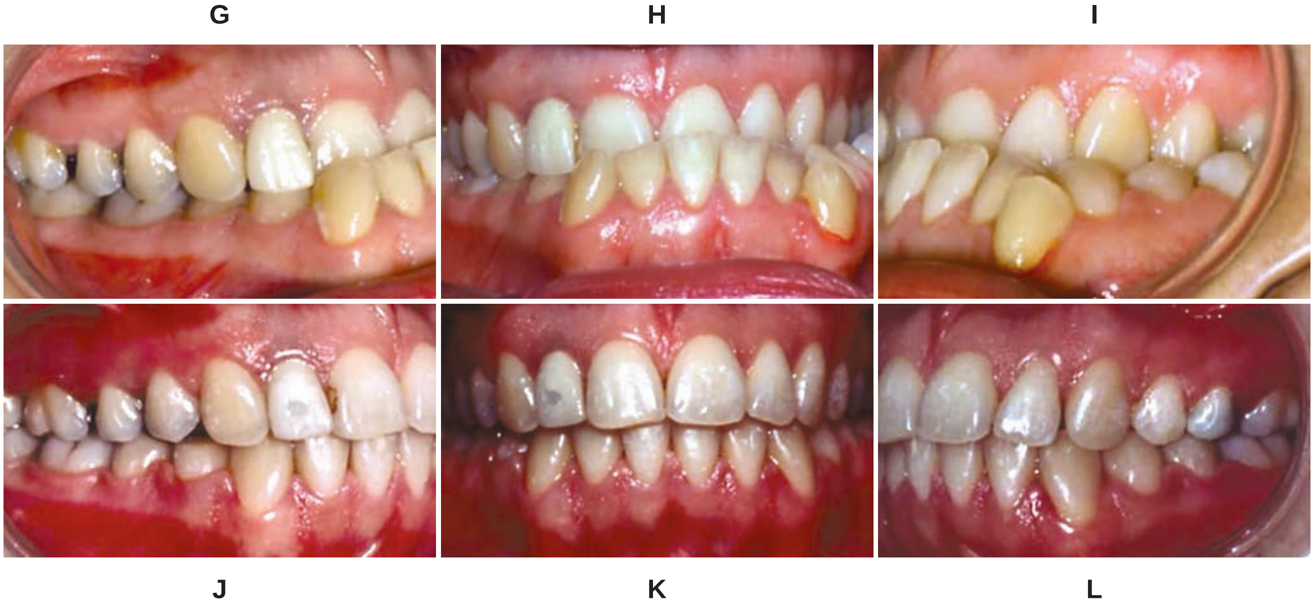

FIGURE 25-25, cont'd **G–I,** Intraoral pretreatment photographs showing malocclusion. **J–L,** Intraoral posttreatment photographs showing optimal correction.

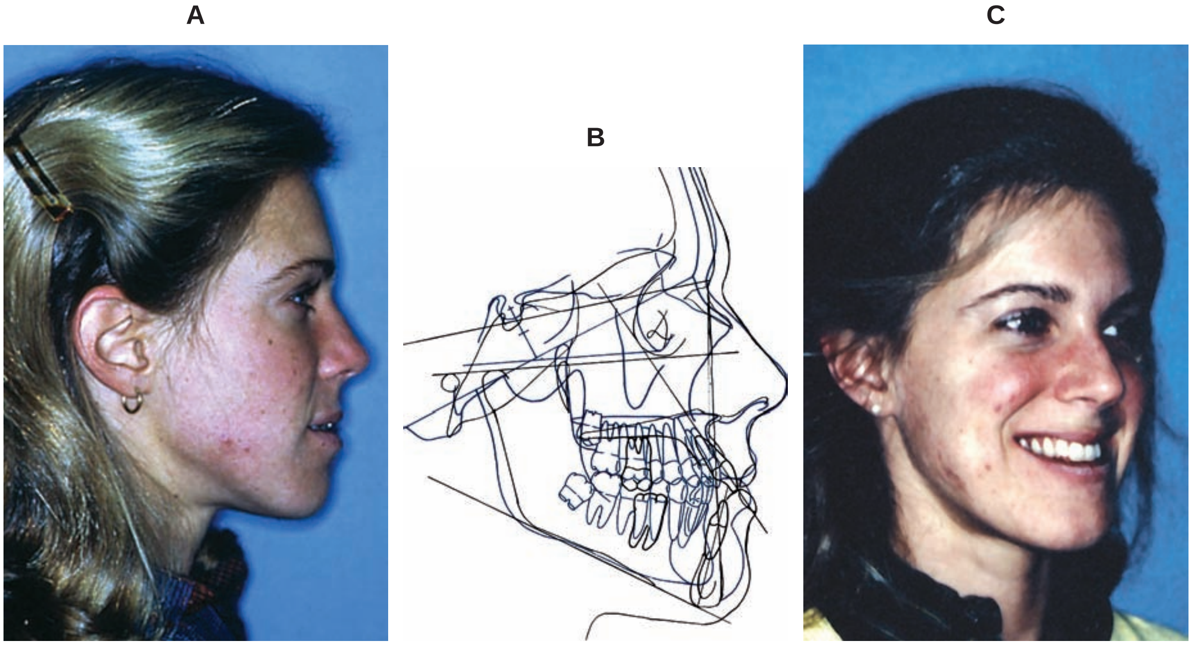

FIGURE 25-26 Patient: AL, 25 years 6 months, female

Classification: Class III skeletal condition with mild alignment problems and no incisor occlusion

Qualification: Mandibular excess with a high mandibular plane angle

Quantification: Mandibular horizontal excess with maxillary posterior vertical excess and an anterior open bite+

Severity: 8.5 of 10; the condition is a multifaceted problem complicated by muscle and joint pain and severe gingival deficiency in the lower anterior and upper posterior areas

Prognosis: 2 of 10; significant improvement can be achieved with successful interdisciplinary therapy using proper temporomandibular dysfunction management, orthodontic and surgical treatment, and periodontal grafting procedures

This patient was highly motivated and complied with the provider team's interdisciplinary treatment recommendations. Her condition responded well to the therapy, as can be seen in the posttreatment photographs. **A,** Pretreatment profile photograph. **B,** Bolton template-guided diagnosis and treatment plan. **C,** Pretreatment facial photograph.

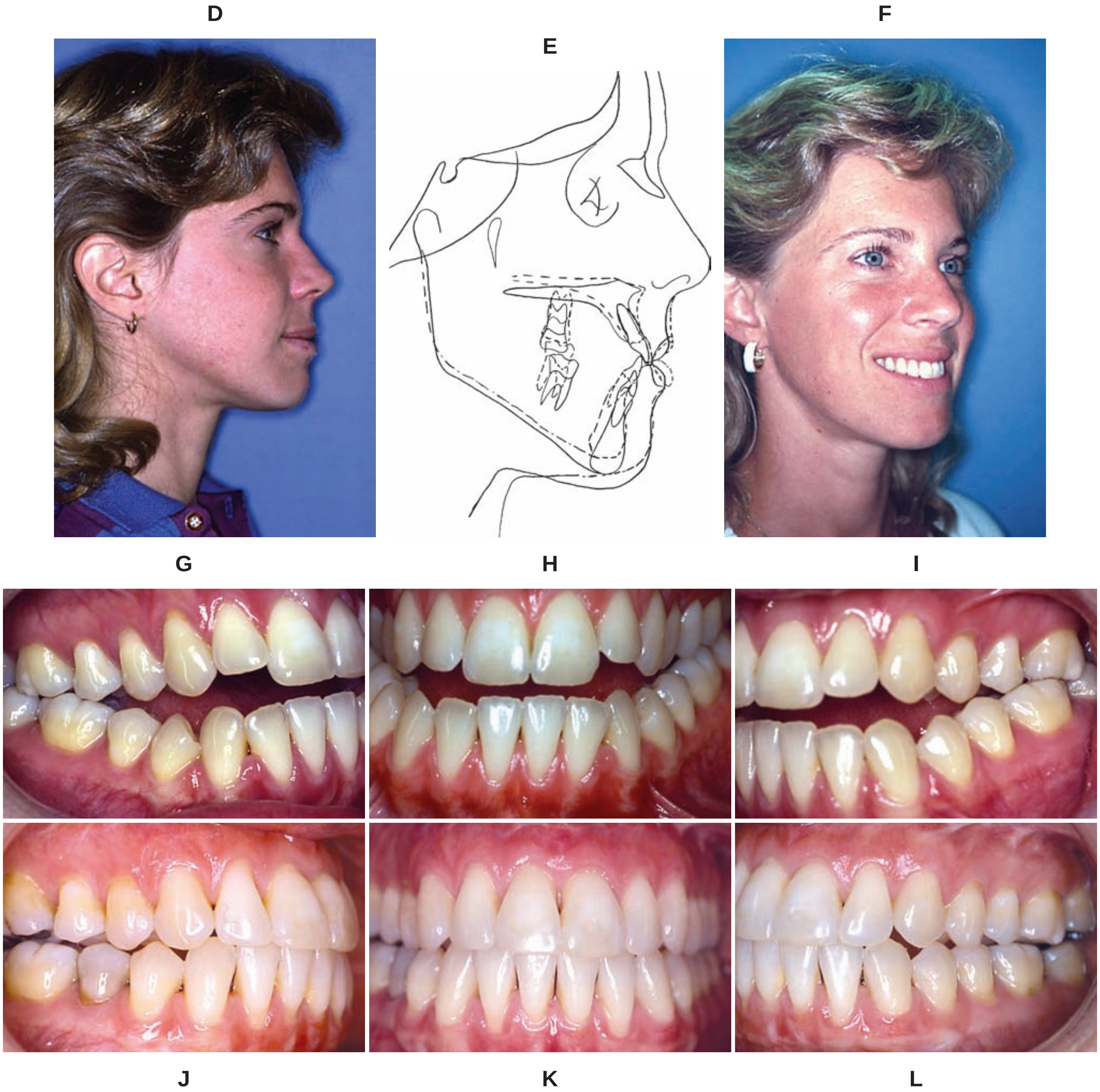

FIGURE 25-26, cont'd **D,** Posttreatment profile photograph. **E,** Cephalometric superimposition. **F,** Posttreatment smile photograph. **G–I,** Intraoral pretreatment photographs showing malocclusion. **J–L,** Intraoral posttreatment photographs showing optimal correction.

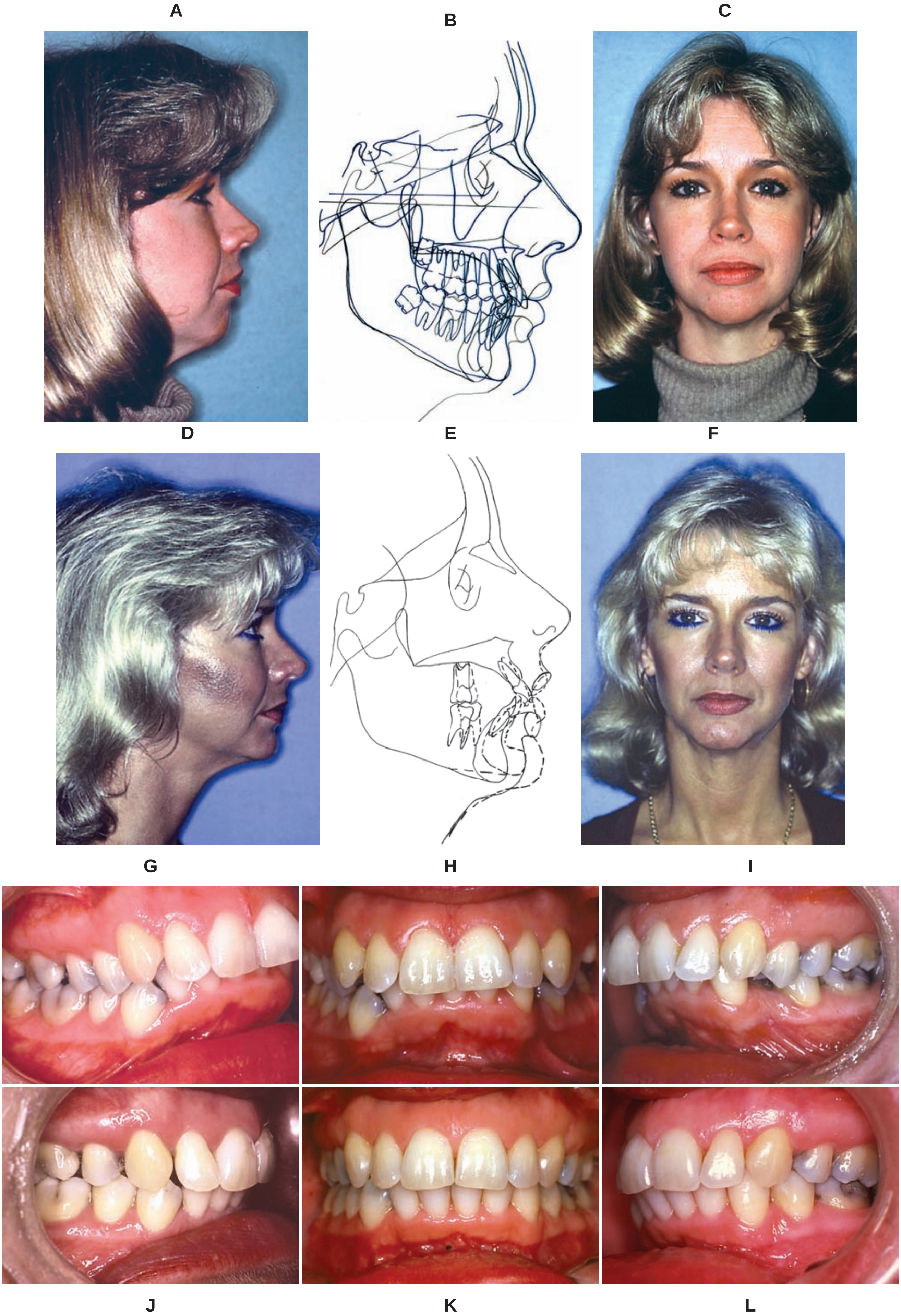
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FIGURE 25-27 **A,** Pretreatment profile photograph. Note protrusive lip and minimal throat/chin definition. **B,** Patient tracing with Bolton template indicates maxillary dentoalveolar protrusion and mandibular deficiency with chin deficiency. **C,** Pretreatment facial photograph. **D,** Posttreatment profile photograph showing improved throat/chin definition because of soft tissue "stretch" from successful chin implant. **E,** Superimposition of lateral cephalogram tracing showing dental retraction of upper incisors (camouflage skeletal Class II) and improved hard and soft tissue in chin area. **F,** Posttreatment facial photograph. **G–I,** Pretreatment intraoral photographs. **J–L,** Posttreatment intraoral photographs.

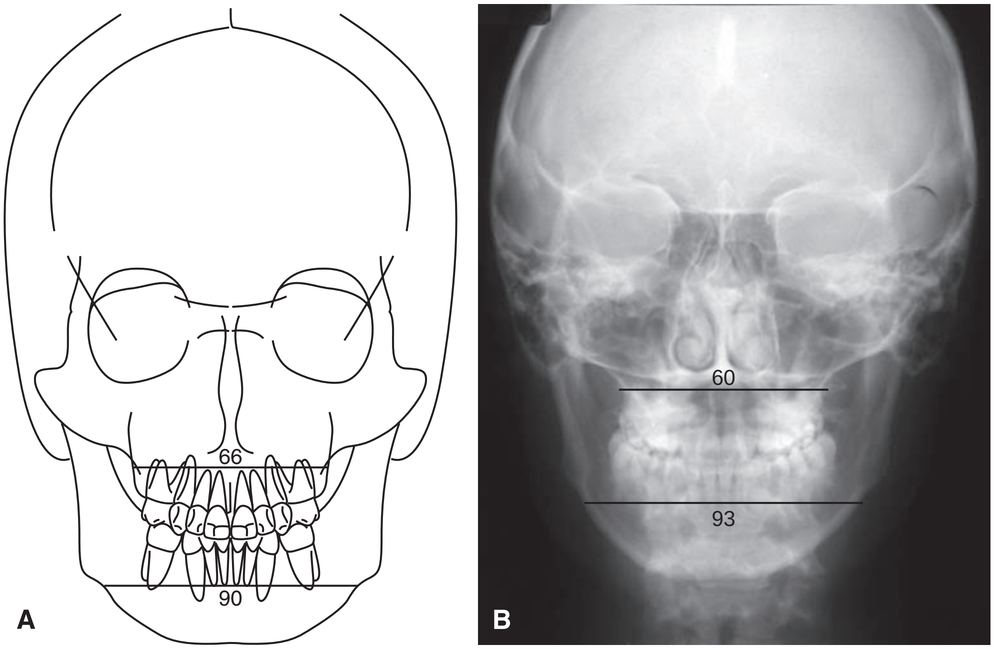

FIGURE 25-28 **A,** Composite frontal tracing of Bolton Standard for adults. The normal maxillary width is 66 mm and mandibular width is 90 mm, as measured from 18 adults from 5000 who were determined to be the *Standard* (normal) with a maxillomandibular differential of 24 mm. **B,** Frontal cephalogram of adult female who required orthodontic re-treatment due to inadequate correction of maxillary-skeletal transverse deficiency. This patient had a maxillo-mandibular differential of 9 mm and required surgical expansion in conjunction with her orthodontic therapy.

Diagnosing Class II, Mandibular Deficiency, and Class III, Mandibular Excess. The authors use the expanded version of the Angle classification system to create a more accurate perspective to diagnostic descriptions (Class II, mandibular deficiency—low MPl angle as illustrated in Figure 25-21, or Class III mandibular excess—high angle as illustrated in Figure 25-26). These descriptions are then integrated with the diagnostic steps of quantification and a rating of severity to illustrate diagnostic and treatment differences of the basic types of problems that arise with mandibular deficiency and mandibular excess (see Figures 25-21 to 25-26). In each of these figures, note that the Bolton template is used to show the skeletal deviations from the template ideal. The process of differential diagnosis of the structural problem, then, includes the following steps:

1. **Classification:** The condition is assigned to a category of Class I, II, or III (Angle's traditional system of classification still is important and can help with codification for insurance purposes).
2. **Qualification:** The problem location is determined (i.e., Is the problem in the upper jaw only? The lower jaw only? Is it all skeletal, or part skeletal and part dental?).
3. **Quantification:** The extent to which each jaw contributes to the problem is determined by percentage or in millimeters.
    - **Severity:** A scale of 0 to 10 provides a rating of the severity of anteroposterior, transverse, and vertical problems, as well as of tooth alignment, dental pathologic conditions, TMJ status, psychosocial factors, and the patient's degree of motivation. Although each problem could be rated individually, the concept of using one number to rate the whole constellation of problems helps the patient understand, in a relative way, the severity of the current condition. A rating of 0 means that

    conditions are ideal or that no problems exist, whereas a rating of 10 indicates a severe dentoskeletal imbalance with possible pathologic sequelae. This number also can be used to project the prognosis for the outcome of the various treatment options under consideration

4. **Prediction of the prognosis** (This may vary depending on the treatment plan chosen)
    - Again using the visual analog scale (0 to 10), it is helpful to predict the improvement of the patient's condition based on the treatment plan. For example, a patient with a transverse problem who accepts surgical expansion may improve from severity of 7/10 to 1/10 with surgery but only improve to a 5/10 without surgery.

Treatment Planning Options

With the safety of jaw surgery techniques improving as a result of modifications in surgical approaches and with anesthetic procedures becoming more sophisticated, orthognathic surgery can be exciting and confusing to the orthodontist and the patient. When a patient has a problem in which both the maxilla and mandible are major components of the problem, both jaws may require surgery. If the patient accepts the optimal treatment plan, and when the result achieved matches the patient's, orthodontist's, and maxillofacial surgeon's expectations, great outcomes result (see Figures 25-8, 25-11, and 25-12).

- Treatment planning options for cases with *skeletal (basal bone discrepancy) components* affecting the malocclusion:
    1. Mild skeletal factors—comprehensive orthodontics is generally effective
    2. Moderate skeletal factors (with growth)—comprehensive orthodontics + orthopedics + camouflage with the need to periodically reevaluate the response while growth proceeds[82]
    3. Moderate skeletal factors (without growth)—comprehensive orthodontics + camouflage + skeletal anchorage to amplify the camouflage effort[83]
    4. Moderate to severe skeletal factors—comprehensive orthodontics + one-jaw surgery
    5. Severe skeletal imbalance—comprehensive orthodontics + one- or two-jaw surgery; considerations for two-stage orthognathics if transverse discrepancy is also severe
    6. Moderate skeletal (without growth) and moderate to severe skeletal factors with dentoalveolar components—may be candidates for SFOT, as discussed previously in this chapter and presented by Roblee, Bolding, and Landers.[55]

Indications for Camouflage Treatment. To illustrate the treatment planning process further, one should be able to answer this question: What makes a borderline orthodontic/surgical case into a successful camouflage treatment? Craniofacial characteristics only make up part of several important considerations in determining the effectiveness of camouflage treatment (see Figures 25-1 and 25-29, and also Box 25-4).

Other important considerations include the following:

1. Moderate basal bone discrepancy as determined by conventional cephalometric standards
2. Double jaw involvement in the discrepancy; that is, 50% of the skeletal problem is due to maxillary anteroposterior excess, and the remaining 50% of the anteroposterior problem is related to mandibular deficiency (preferably with some chin contour). This allows the appearance of a more balanced soft tissue profile in the presence of a large anteroposterior discrepancy, thereby allowing more latitude for dental compensations. One effective mechanism to assess this discrepancy quantitatively is by comparison of the patient's cephalogram to the Bolton template using nasal superimposition and Frankfurt Horizontal (FH) parallel to the patient's FH (see Figure 25-1)[84]
3. Adequate alveolar bone and gingival tissue for incisor reangulation. Sometimes gingival grafting procedures are indicated to allow for the compensatory movements, and this is usually acceptable to achieve proper incisor guidance.
4. Patient acceptance of the possibility of long-term lingual arch bonded to mandibular anterior teeth

In the successful planning for camouflage treatment, the foregoing factors determined by template-guided diagnosis and evaluation help to define the orthodontist's treatment planning limits without surgical intervention and give the patient an opportunity to consider available treatment alternatives.

Contraindications to Camouflage. When treatment planning moderate skeletal imbalances, one should be aware, however, that not all borderline cases can accommodate camouflage treatment planning. In general, camouflage therapy would be contraindicated when single-jaw imbalances are severe; that is, a patient demonstrates, on clinical evaluation and cephalometric measurement confirmation, that the total skeletal Class II malocclusion is secondary to mandibular deficiency (see Figures 25-2 and 25-21 to 25-23). While an incisal relationship may be achieved with camouflage treatment, the resulting profile would be imbalanced; the upper incisors would be excessively retroinclined and the lower incisors excessively proclined to achieve incisal contact. The skeletal Class II case in which there are both maxillary and mandibular deficiencies (relative to nasal superimposition) is another case type for which camouflage treatment planning should be avoided. This case type is seldom presented in the literature unless it is referenced to sleep apnea in which both maxillary and mandibular surgery is medically indicated.[15,84]

Upper and Lower Jaw Skeletal/Dental Problem

The orthodontist should consider the following three steps in addressing a skeletal-dental problem of the upper and lower jaws:

1. Discuss treatment options—conventional and expanded options including skeletal anchorage[85] to enhance dentoalveolar changes as well as SFOT.[55]
2. Analyze anticipated outcomes.
3. Consider the tradeoffs that may result from nonorthognathic surgery management

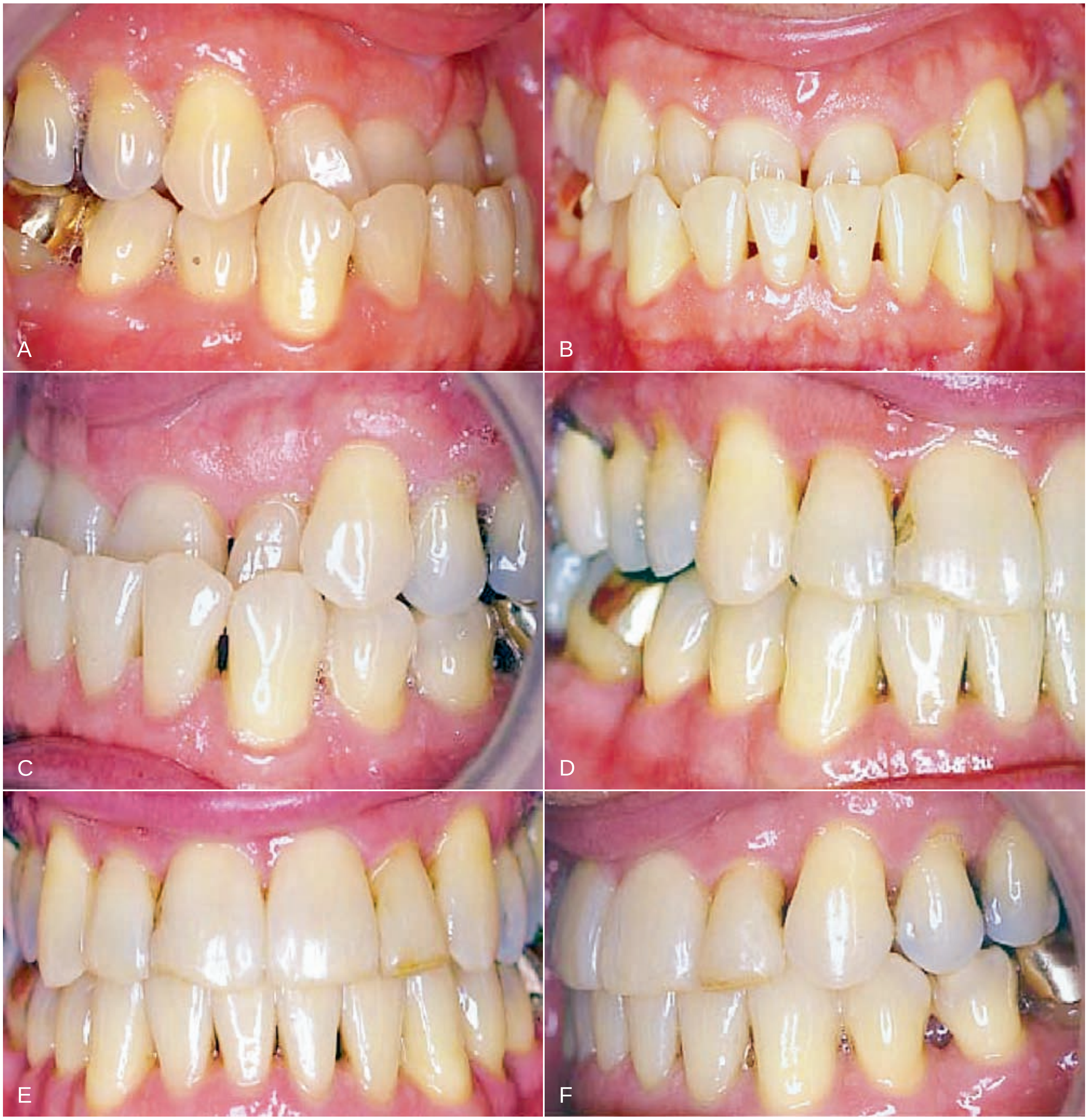

FIGURE 25-29 **A–C,** Intraoral photographs prior to any orthodontic treatment. Note degree of anterior crossbite in this 62-year-old man. This functional imbalance is now causing tooth fracture and accelerated wear. **D–F,** Intraoral photographs after orthodontic treatment. Principles of therapeutic diagnosis were applied to determine if nonsurgical, or camouflage, treatment could be incorporated to solve this long-standing bite problem. While a significant skeletal imbalance was present, the skeletal Class III problem was made worse due to incisal prematurity that forced the patient to shift his mandible forward 4 mm.

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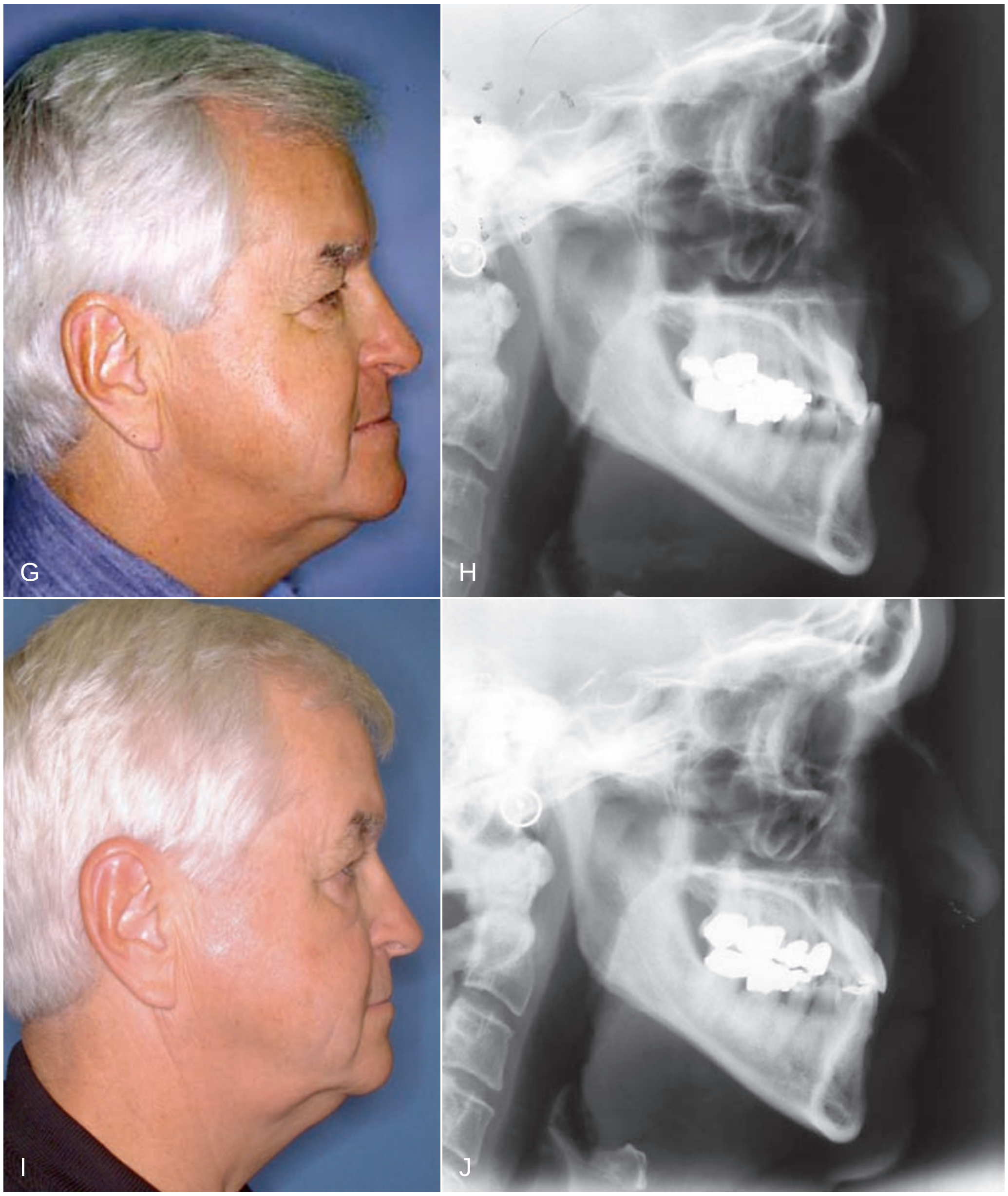


FIGURE 25-29, cont'd **G–H,** Pretreatment profile photograph and pretreatment lateral cephalogram, respectively. **I–J,** Posttreatment profile photograph and posttreatment lateral cephalogram, respectively.

Therapeutic Diagnosis of Borderline Cases. Because of the range of treatment plan options, the concept of therapeutic diagnosis is even more important today than when it was first introduced. Ackerman and Proffit clarify this diagnostic approach in the following quotation:

> Therapeutic diagnosis is not a substitute for established procedures, nor should it become a cover for fuzzy thinking and diagnosis. Where uncertainty exists despite a careful diagnostic evaluation, there is danger in formulating a rigid treatment plan. Systematic evaluation of the initial response to orthodontic treatment can help a great deal in making the difficult diagnostic and treatment planning decisions, especially as concerns the basic question of extraction or nonextraction. Borderline cases in which the treatment response should be considered before one decides to extract are more common than many diagnostic systems indicate. It is strength, not weakness, to recognize true uncertainty.[86]

The process calls for the use of therapeutic aids indicated in Table 25-5. Borderline surgical-nonsurgical cases often require initial therapy, followed by appropriate new records and reevaluation to allow a thorough review of treatment compromises if the surgical approach is not undertaken. A case may be a definite surgical case but borderline in terms of the number of osteotomies. Consideration of obtaining a practical, safe objective versus achievement of a hypothetic ideal is important.

BOX 25-4 Camouflage Checklist for Class II Patients

- Skeletal malrelationship with Wits differential +4 mm or greater
- Bolton template superimposition (as described in this chapter)
- With almost equal portions of the Wits differential being contributed by maxillary basal (measured by "A" point) excess and mandibular deficiency (measured by "B" point) compared to the template. When the skeletal differential is present because of each jaw playing a part, as it relates to the nose—camouflage can more easily occur without having deleterious effects on soft tissue aesthetics. In other words, after upper premolar extractions facial balance continues to be proportionate.
- If the ceph shows a Wits differential of +7, for example, and the template shows that the differential is all because of mandibular deficiency, camouflage therapy may help reduce the overjet, but it will result in overretraction of the upper incisors, require a great deal of incisal root torque (possible root resorption) and will accelerate the aging of the face.
- Moderate upper incisor crowding and minimal lower incisor crowding also helps to justify camouflage because correcting the anterior alignment limits the degree of retraction and there is less impact on negative soft tissue changes of the upper lip.
- Patient acceptance of the possibility of long-term bonded lingual arch to lower anteriors
- If slightly more of the mandibular deficiency (Class II) is in the mandible, then to preserve upper lip support the lower incisors may have to be compensated (proclined) more. In such cases the amount of attached gingival of the lower anterior segment needs to be assessed. If the tissue is thin or deficient, gingival grafting may be needed to avoid gingival recession during proclination. In addition, the long-term stability of the lower anterior segment may require life-time bonded lower lingual arch.
- Another consideration is the aesthetic balance of the chin. Is there enough chin to create facial balance? Will proclination of the lower incisors reduce the effective chin to an undesirable aesthetic position? Should advancement genioplasty be considered and discussed with the patient? How much less risk does the advancement genioplasty carry than a mandibular advancement in this case?
- Stability of the outcome should also be included in the considerations of which treatment plan would serve the patient the best. With the above considerations, non-growing Class II, Div 1 patients with maxillary dentoalveolar protrusion, moderate maxillary crowding, and minimal mandibular deficiency are good candidates for successful camouflage therapy with upper premolar extractions.

TABLE 25-5 Therapeutic Aids

Appliance	Used to Assess	Duration
Bite splint	Neuromuscular habits and deprogramming muscles of mastication	1 to 6 months; reevaluate new cephalogram and mounted study models
Superior repositioning splint High-pull headgear orthopedic effect limited to growing patient	1. Degree of patient cooperation 2. Orthopedic response of Class II with vertical maxillary growth	6 to 12 months (possibility of continuation)
DeLaire face mask	1. Orthopedic response in Class III with mild to moderate maxillary deficiency 2. Maxillary horizontal growth acceleration	6 to 12 months (possibility of continuation)
Chin cup	1. Orthopedic response in Class III with mild mandibular excess 2. Restraint or redirection of mandibular growth, primarily in early years 3. Reprogramming of jaw muscles with pseudoskeletal Class III problems	6 to 24 months
Fixed appliances to level and align (also test compliance with cervical or high-pull headgear)	1. Combination maxillary protrusion and mandibular deficiency (Class II, Division 2 type) 2. Upper lip contour and option between upper premolar extraction and mandibular advancement	6 months

In essence, borderline surgical cases have moderate skeletal malrelationships that affect both jaws equally; an example would be Class II maxillary protrusion and mandibular deficiency (see Figure 25-27). In such cases, dental camouflage rather than surgical correction may be considered appropriate. Another example of a borderline case is a situation in which a surgical plan has been selected and a decision must be made between two-jaw and one-jaw surgery. For example, a Class III mandibular excess and vertical maxillary excess with a moderate mandibular asymmetry may get the best result with double jaw surgery. An alternative procedure with one jaw surgery would leave the vertical excess uncorrected. Sometimes the added risks of a double-jaw procedure, in relation to the minor gains anticipated, make a single osteotomy the procedure of choice. Occasionally a patient will present with a situation that appears to require two-stage surgery (Stage I for the skeletal transverse discrepancy and Stage II for the anteroposterior and vertical problem). The patient illustrated in Figure 25-30 was treatment planned as a two-stage surgical patient, but following the surgically assisted rapid palatal expansion (SARPE) procedure, her open bite continued to improve to the point that we agreed to camouflage the Class II open bite with conventional orthodontic treatment.

Key Considerations of the Integrated Treatment Plan

Once both the orthodontist and the surgeon have determined that a patient is ready for surgery, the surgeon will create a surgical prediction tracing or STO (surgical treatment objective) and model surgery.[50] There are now

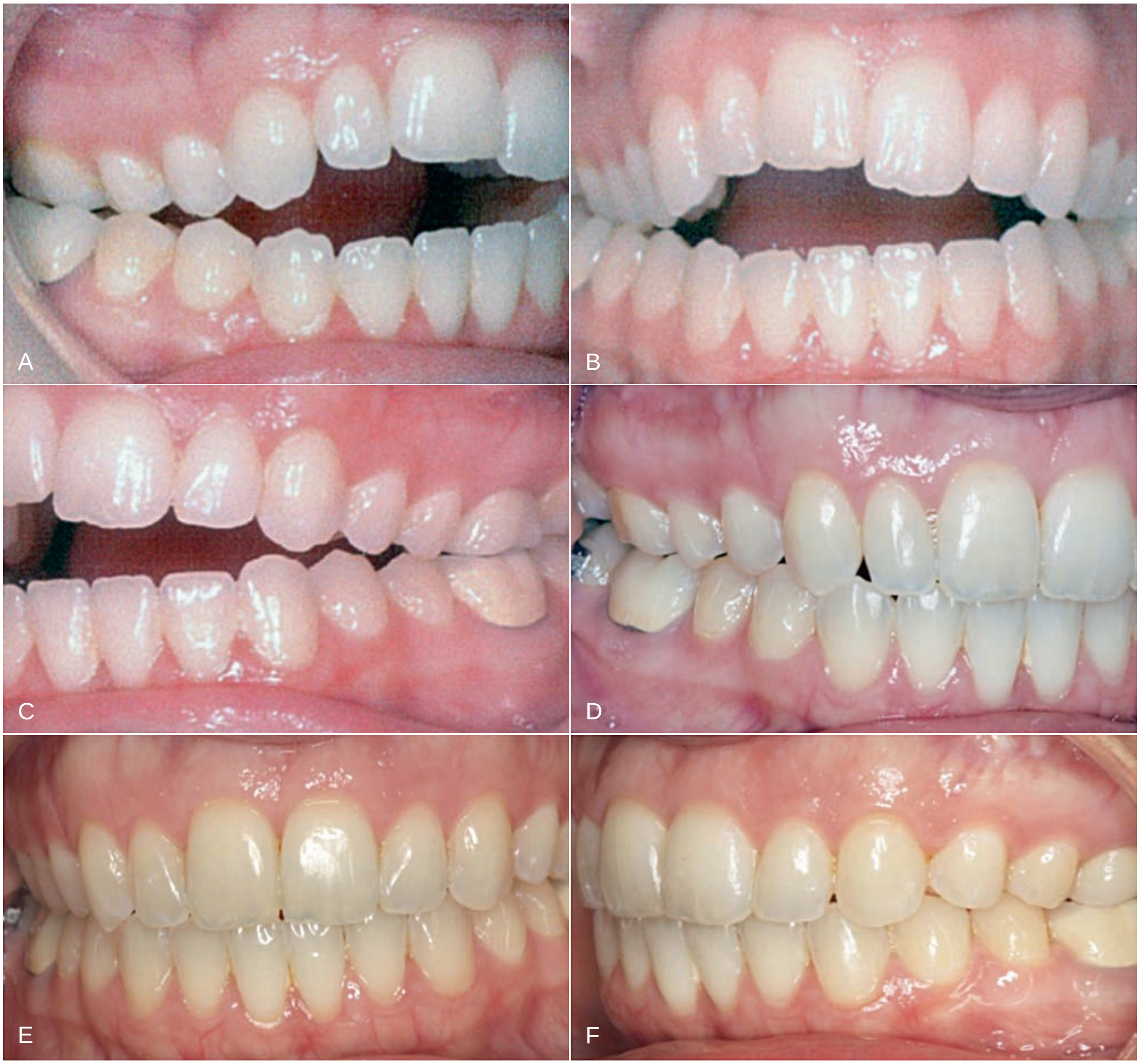


FIGURE 25-30 **A–C,** Intraoral photographs prior to any orthodontic treatment; note degree of anterior open bite and arch constriction with posterior crossbite. Incisor position is consistent with an ankylosed #8. Previous trauma to #8 and #9 area was ruled out and percussion test for ankylosis of #8 or #9 was negative. **D–F,** Intraoral photographs after orthodontic treatment and orthognathic surgery. This patient was originally treatment planned for two-stage surgery. She responded sufficiently well to stage I surgery of surgically assisted rapid palatal expansion (SARPE) procedure and orthodontic movement that the patient, the surgeon, and the orthodontist agreed to complete treatment without the second-stage LeFort procedure that was anticipated.

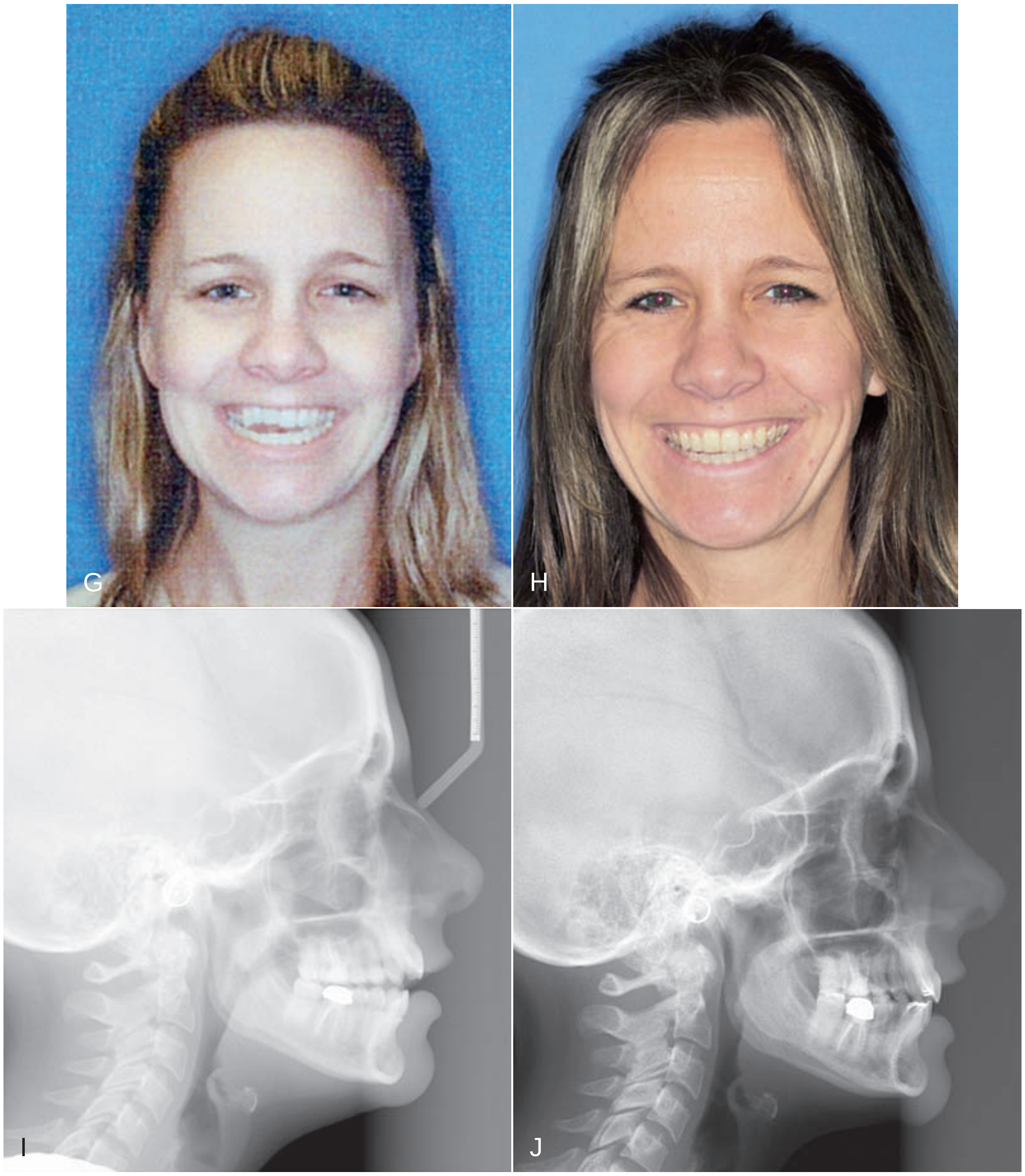


FIGURE 25-30, cont'd **G–H,** Frontal facial photographs showing pretreatment smile and posttreatment smile, respectively. **I–J,** Lateral cephalograms illustrating pretreatment and posttreatment smile, respectively. Initially, incisor position showed that the incisor could be erupted to allow more incisal display. Long-term stability and soft-tissue (tongue) adaptation is being monitored. Long-term tongue crib may be indicated.

many computer programs that allow the surgeon to digitize a cephalometric radiograph and create a prediction tracing. These programs allow movements in any direction by entering the amount of movement at a given cephalometric point. Another method is to trace a cephalometric radiograph and create tracings on acetate paper to predict the surgical movement. The benefit of this method is that it provides a visual road map that can be used during the surgery as a guide to the desired result. A sample case is provided with the steps involved in creating the STO (see Figure 25-14).

Step-by-step instructions are presented in Box 25-5. This method shows the skeletal movement anticipated by moving the skeletal structures to normal positions using the patient's cephalometric tracing and simulating the surgical movements. The magnitude of movement is shown at the reference lines both in the anteroposterior and vertical directions. The soft tissue is drawn and is variable, but most studies indicate that the anteroposterior movement of the upper lip is 50% of the skeletal movement.[51]

The image from three-dimensional capture software shows no significant difference between the lateral cephalometric images when superimposed[87] (see Chapter 4).

A common occurrence in daily practice for orthodontists is *to guide* their patients toward a surgical treatment

BOX 25-5 **Orthognathic/Orthodontic Treatment Milestones for the Typical Orthognathic Surgical Patient**

Evaluation (2–3 mo)
- Orthodontic records:
- Diagnosis/treatment plan
- Surgical consultation

Presurgical Orthodontics (6–18 mo)
- Presurgical alignment
- Presurgical records
- Presurgical reconsult with surgeon

Surgical Treatment
- Orthodontic placement of surgical wires/hooks
- Surgical correction
- Postsurgical records/reevaluation

Postsurgical Orthodontics (6–12 mo)
- Postsurgical tooth alignment to finalize bite correction
- To complete arch coordination

Retention/Observation (12–18 mo)
- Observe tooth "settling"
- Monitor retainers
- Bite adjustment as needed

plan *or away from* a surgical treatment plan. This guidance depends on the orthodontist's training, personal experiences, professional experiences, diagnostic data, and a clear awareness of the variable goals of treatment based on individual patient treatment requirements. In addition, the surgical or nonsurgical treatment planning decision often is made with the patient's own process of gathering detailed treatment information, a careful determination of the patient's own goals for comprehensive treatment, and, in many cases, on the availability of insurance coverage to assist in the fees for surgical aspects of treatment. As a result of this multilayered decision-making process, the orthodontist must define goals with the patient and establish a plan, not just present a plan to the patient.

Borderline orthodontic cases provide orthodontists with excellent examples of the benefits of setting mutually defined treatment goals. The strategy for treating borderline orthodontic cases with camouflage therapy is to create dentoalveolar changes that will compensate for a skeletal base imbalance. Although clinical orthodontists commonly use this approach in treatment planning, there is a limit to how much dentoalveolar change can compensate for an imbalanced skeletal structure. To discuss the limits of camouflage properly, one must define the goals of treatment clearly. Because orthodontic treatment is elective, the orthodontist and the patient must visualize the goals of treatment in the same way. The orthodontist, for example, may have a clear concept of goals for treatment as taught during the orthodontic graduate program. However, orthodontic providers must individualize the treatment goals for each adult/surgical patient through a detailed interview process that starts at the initial examination appointment and continues through the review of the diagnostic records at the treatment planning conference with the patient.

The treatment planning process for patients with malocclusions plays a pivotal role in guiding the patient to a treatment that will satisfy his or her short-term concerns and long-term functional requirements and establish reasonable stability. Although the three steps listed previously seem simple, in several specific treatment planning modalities orthodontists must strive to gain expertise to achieve maximal effectiveness. With each of these modalities, the orthodontist should be able to answer the following pertinent questions:

1. **Clarification and individualization of treatment plan for patients with skeletal malocclusion**
   - Is it imperative that every patient be guided to a treatment plan exemplifying a textbook ideal result?
   - When will a "practical," nonsurgical result suffice?
   - Whose concept of facial aesthetics and balance takes precedence: that of the patient, the orthodontist, the surgeon, the parent(s), or the significant other?
   - Is it acceptable to achieve stability with mechanical approaches (e.g., lifetime bonded retainers, lifetime removable retainers, or both)?
2. **Differential diagnosis**
   - What is a borderline surgical case? What are the risks if a patient with a severe skeletal problem does not accept surgery?
   - At what point does a stomatognathic system skeletal imbalance change from a nonsurgical problem to a surgical problem?
   - Is the surgical/nonsurgical decision made by the patient, the orthodontist, the surgeon, or the insurance company?
3. **Extractions**
   - Will extraction of teeth be effective for orthodontically camouflaging the malocclusion?
   - Is extraction of premolars needed to decompensate a condition before surgery?
   - Is extraction of premolars being planned for alignment purposes only?
   - Should molar or premolar extraction be planned to maximize autorotation of the mandible?
   - What happens when several of these extraction considerations are applicable to one patient?
   - Should the extraction decision be made even though the final treatment plan has not been defined?
4. **Is there a clear cephalometric measure of an "acceptable compromise?"**[30]
   - Can patients with a +5 degree or greater ANB difference (A point–nasion–B point) or a −3 degree

ANB difference have an acceptable result without surgery? If so, under what conditions?

- Should the concept of acceptable compromise be redefined with the understanding of new surgical capabilities?

5. **Visualized treatment objectives**
    - Can cephalometric predictions be achieved routinely?
    - Do patients have an overly optimistic perception of the outcome? [17,32]
    - Will computerized three-dimensional predictions be an integral part of visual treatment objectives in the future (see Chapter 1)?[82,88]
    - Is computerized imaging a treatment planning tool, a marketing tool, or both? [72]
    - Are a patient's presurgical expectations a predictor of postsurgical satisfaction?
6. **Patient expectations**[22,28,29,89,90]
    - What percentage of surgical-orthodontic patients eventually indicate that they are satisfied with the treatment outcome?
    - Are immediate postsurgical patients prone to be less satisfied than expected? If so, why?
    - Will the planned procedures affect facial aging?

Treatment Timing. The orthodontist generally is the key person in deciding the appropriate time to initiate treatment plans that fall into one of the following categories:

1. Orthodontic only
2. Orthopedic and orthodontic (growth modification)
3. Orthodontic and surgical
4. Independent arch alignment with nighttime splint therapy to provide interim occlusal "balance"

General concepts that are accepted for specific treatment problems are reviewed in this section. The principles presented must be applied to each individual patient.

Treatment Timing for the Maxillary Deficiency Patient. Deficiency of the maxilla with anteroposterior and transverse components is managed best in the mixed dentition stage. The orthopedic effect is predictable, and the early treatment staging enhances the environment for future harmonious growth. The early permanent dentition stage is not too late to plan treatment for many patients with maxillary deficiency, but the stability of the results may be less than if the patient were treated earlier (see Chapter 14).

Treatment Timing for the Mandibular Excess Patient. Patients with a family history of moderate to severe mandibular excess and who demonstrate growth patterns coincident with mandibular growth imbalance are treated best when growth is complete, as verified by wrist films and head-plate superimposition (Figure 25-31).[91]

An important note is that some patients have mild mandibular excess, mild maxillary deficiency, and a functional forward shift of the mandible (see Figure 25-32). The combination of these factors creates the clinical appearance of a severe Class III mandibular excess pattern. Accurate recording of mandibular position, early orthopedics, and some compensatory camouflage (compensate upper incisor labially and lower incisor lingually) may allow satisfactory nonsurgical management. This type of patient benefits from therapeutic diagnosis and periodic reevaluation of growth. One must take care not to overtreat these patients orthodontically through camouflage if the mandibular excess growth continues. Orthodontic overtreatment can lead to an unstable result, traumatic incisor occlusion, incisor mobility, and gingival recession (Box 25-6, Phase I, Orthodontic Milestones).

Assessment of the growth treatment response vector (GTRV) (see Figure 25-31) is an important tool to be used by the orthodontist when trying to determine if a Class III mandibular excess and Class III maxillary deficiency patient is growing outside the range of nonsurgical correction.[92,93]

Treatment Timing for Mandibular Deficiency Patients.

> The degree of mandibular deficiency (mild, moderate, or severe) and the type of the deficiency (type I [low angle], type II [medium angle], or type III [high angle]) are factors in deciding the timing of treatment.

Most orthodontists attempt conservative (nonsurgical) measures in the 14- to 16-year-old age group to limit maxillary horizontal growth and enhance mandibular growth. The mandibular growth rate slows earlier in girls than in boys. Therefore, for girls who have severe cases of pure mandibular deficiency or mandibular deficiency with asymmetry, surgery can be recommended along with orthodontic treatment in this age group.[94,95]

BOX 25-6 PHASE I Orthodontic Milestones for Patients with Skeletal Components to Their Malocclusion (Ages 4–12)

Evaluation (1–3 mo)
- Orthodontic records
- Diagnosis/Treatment plan

Appliances in Place (12–18 mo)
- Growth & treatment response monitored (patient cooperation is essential)
- Remind parents/patients of the importance of compliance

Observation (6–12 mo)
- If favorable progress, go to stabilization program
- Evaluate growth treatment response vectors (GTRV)

Periodic Recall (18–24 mo)
- Continue growth guidance and monitor dental development
- Reevaluate GTRV

Phase II
- Evaluate for new problems
- Full braces to complete bite correction
- Additional orthopedics possible
- If poor response—wait and plan orthognathics

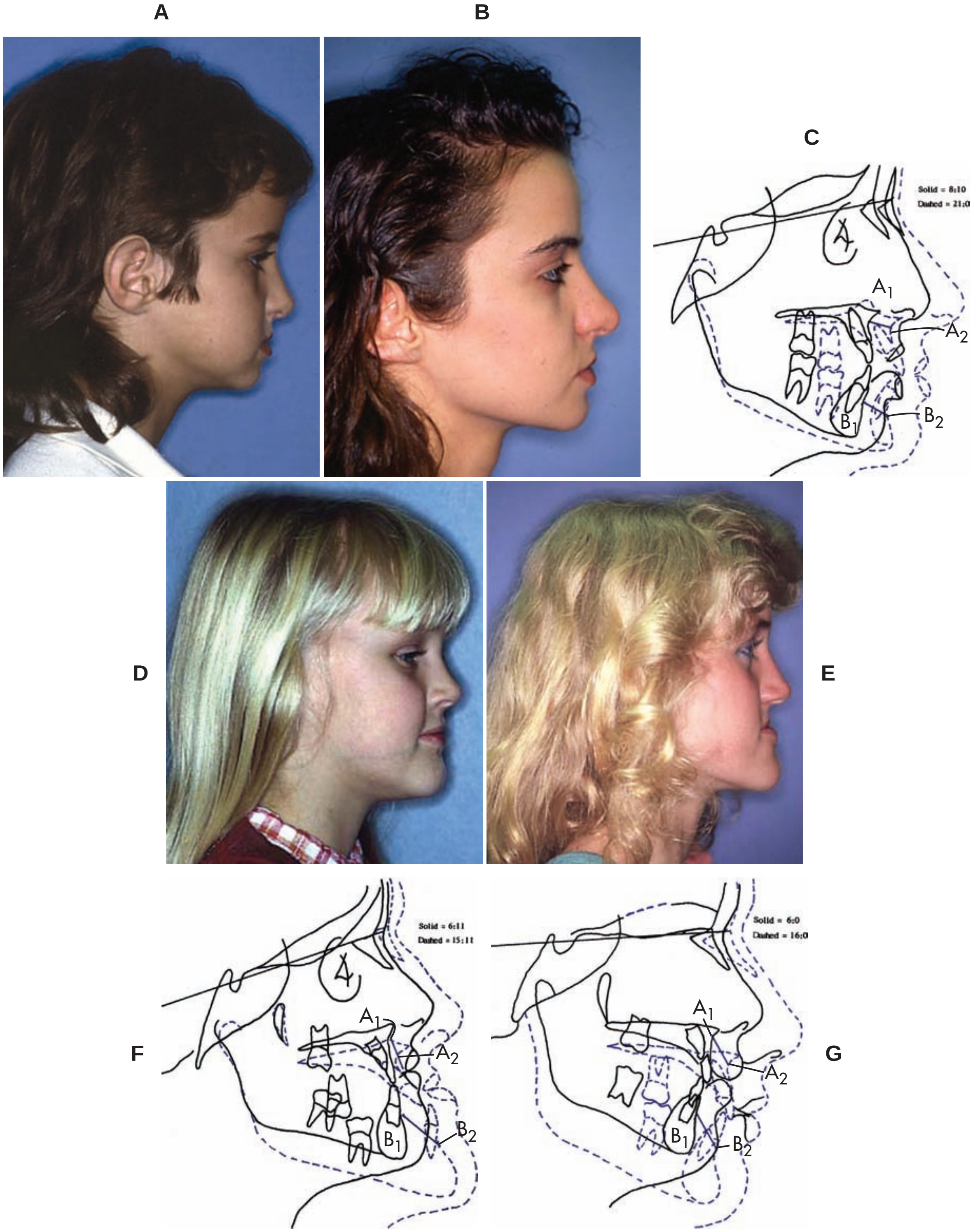


FIGURE 25-31 **A,** Pretreatment profile photograph of an 8-year-old patient who had full Class III malocclusion with anterior crossbite. She was treated with two-stage Class III orthopedics and orthodontics. **B,** Profile of same patient at age 21. Acceptable facial balance was achieved without surgical intervention. **C,** Cephalometric superimposition. Note favorable response because of early correction and favorable maxillary (*A1–A2*) and mandibular (*B1–B2*) growth vectors. **D,** Pretreatment profile photograph of 7-year-old who had a developing Class III problem. She was treated with Class III orthopedics. **E,** Profile at age 16 showing unfavorable pattern of maxillary and mandibular growth. **F,** Cephalometric superimposition. Note unfavorable response with orthopedic attempt at early correction and unfavorable maxillary (*A1–A2*) and mandibular (*B1–B2*) growth vectors. **G,** Cephalometric superimposition of Bolton template for 6- to 16-year-old standard, illustrating maxillary and mandibular growth vectors for maxilla and mandible in patients with optimal occlusions and having proportionate facial growth.

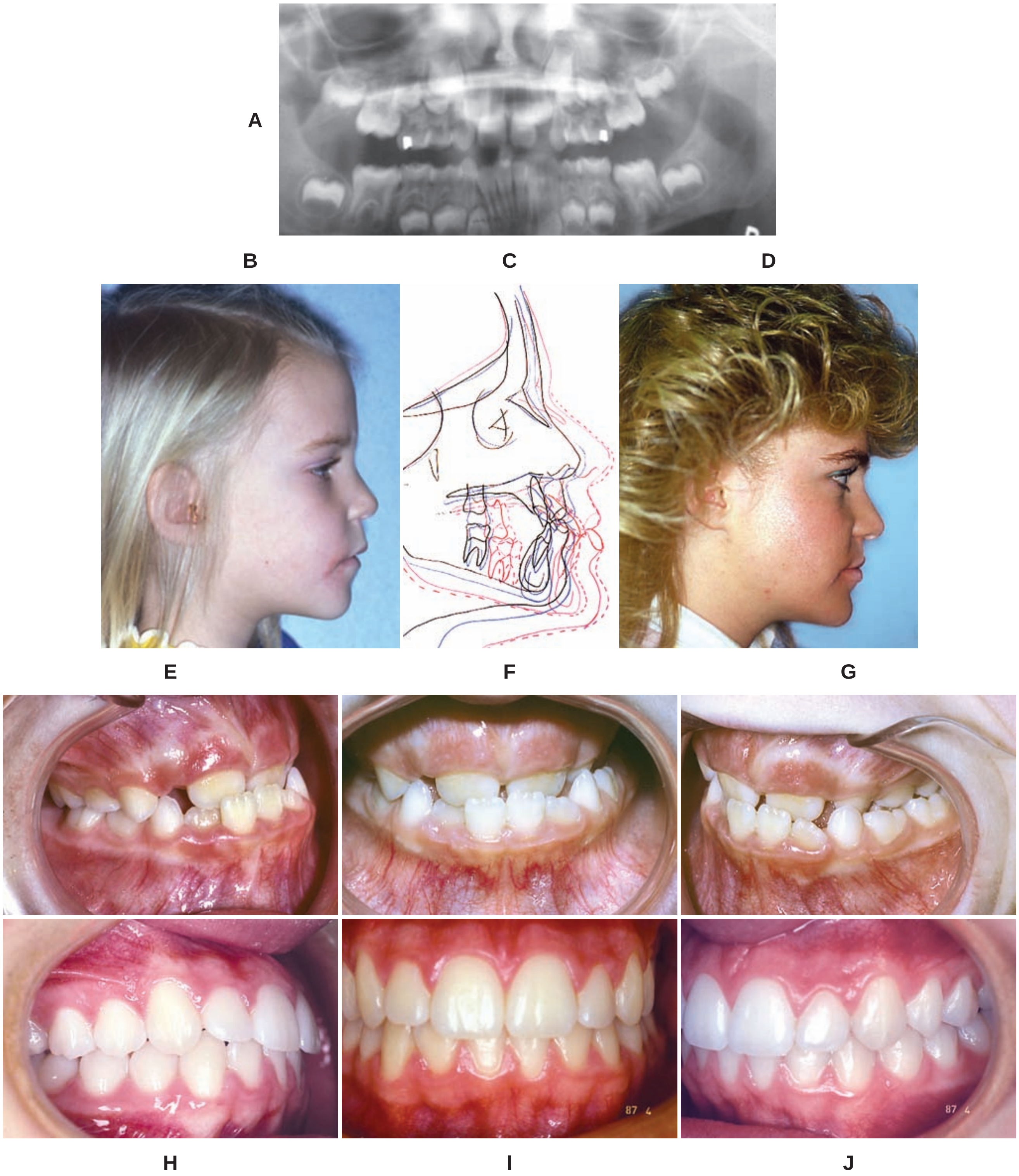


FIGURE 25-32 **A,** Pretreatment panoramic radiograph showing severe maxillary crowding. **B,** Pretreatment facial photograph at 6 years of age. **C,** Cephalometric tracing illustrating skeletal relationship at 6 years old (*solid black*), 8.5 years old (*solid blue*), 16 years old (*solid red*), and 18 years old (*dashed red*). **D,** Facial photograph taken 3 years posttreatment during retention period. **E–G,** Pretreatment intraoral photographs of a 6-year-old girl with the appearance of a significant Class III problem. A functional shift of the mandible to the left and forward has occurred, which makes the problem look worse than it is. **H–J,** Posttreatment photographs illustrating corrected Class III malocclusion. This borderline Class III surgical problem was able to be treated nonsurgically because of early intervention.

In boys, there is evidence of protracted mandibular growth until age 21 to 23 years. Although a mandibular deficiency will not self-correct, the maxillomandibular growth differential can be used with directional force orthopedics to improve significantly many low and medium mandibular plane angles to the point that surgery is not necessary.

With moderate or severe type III mandibular deficiency, boys and girls usually require orthodontics and surgery to achieve facial balance, stability, and good function. The timing of surgical intervention in these cases ultimately depends on (1) growth factors, (2) emotional maturity, (3) self-image considerations, (4) school and work plans, (5) insurance factors, and (6) the patient's and family's perception of relative need.[17,88,96]

Considerations in the Management of Facial Asymmetry

One of the more challenging treatment planning decisions that orthodontists face is the management of facial asymmetry. Key questions must be addressed early in the analysis of the case:

1. Is the developing asymmetry a result of trauma? A careful history must be taken. An excellent discussion of acute care of a condylar fracture can be found in Proffit and White's textbook.[44]
2. Is the asymmetry affecting the maxilla and the mandible? Is it getting worse with time? Panoral radiographs and serial posteroanterior cephalograms, as well as a submental vertex radiograph, are needed to aid in this assessment.
3. Would functional appliance therapy be effective in this case? Some authors have shown good improvement using a functional appliance approach (see Chapter 8). Severe cases of hemifacial microsomia, however, may require orthopedic treatment to prepare for staged surgery to correct the growth imbalance.
4. What is the appropriate timing for surgical intervention? Early consultation with a surgeon familiar with the range of considerations in asymmetry cases is desirable. Periodic functional and emotional assessment also is desirable in preparing the patient for the corrective steps. Orthopedic measures can be taken, but orthodontists need to avoid patient burnout and disappointment if further surgery will be needed, especially in cases of moderate and severe asymmetry (see Figure 25-12).

In patients who have condylar hypertrophy, a scintigraphy analysis (isotope uptake) can help to determine the appropriate timing based on hot spot analysis. Waiting until the hypertrophy burns itself out is the most judicious way to proceed in these cases.

It is important to remember that facial asymmetries can have skeletal manifestations that need to be understood in treatment planning. In an asymmetric face, the body of the mandible may be vertically larger than the opposite side. Although the dentition can be leveled via orthognathic surgery, there still may be a residual facial asymmetry because of a size discrepancy in the mandible. The patient needs to be aware of this discrepancy so that decisions can be made to address the problem. Unilateral disc displacement (UDDN) without reduction may display altered craniofacial morphology and needs to be assessed, especially in growing patients.[97]

SEQUENCE OF TREATMENT FOR THE ORTHOGNATHIC PATIENT

Although many believe that the sequence of treatment starts with the interview and examination of the patient with skeletal jaw imbalance, the most important steps take place long before the surgeon or orthodontist meets the patient. The feedback loop sequence described in Box 25-2 has 17 significant steps that provide the patient and doctors an excellent means of achieving the desired treatment outcome.

Importance of the Sequence

In the sequence of treatment for patients with major dentofacial imbalances (see Box 25-2), steps 1, 2, and 17 are most often underemphasized. Because of this deficiency in private practice, these steps of the treatment sequence are reviewed to emphasize the reasons for their importance.

Step 1: Multiple Provider Team Selection (Interdisciplinary Therapy). The dentist will refer patients with skeletal malocclusion to the orthodontist if the dentist is confident that the patient will receive appropriate state-of-the-art care. The orthodontist must select surgeons who are experienced and well trained in the spectrum of orthognathic procedures. A periodontist, psychologist, and physical therapist may become key team members in selected cases.

Step 2: Goal Clarification. The members of the provider team should share similar concepts of treatment goals. Functional occlusal goals, stability of outcome, and dental and facial aesthetic goals can mean different things to different professionals. Periodic group meetings oriented to individual case analysis offer an opportunity for team members to discuss their concepts of the treatment goals that apply to the individual patient (see Box 25-1).

Steps 3 through 16. Steps 3 through 16 are self-explanatory and commonly are performed by provider groups. By following the general concepts stated in each step, the orthodontist automatically spends time with the patient and can address most of the patient's presurgical and postsurgical concerns.

The orthodontist can explain the sequence of treatment to the patient and the general dentist through the use of a treatment conference report; Figure 24-30 provides an example of the treatment conference report used by the authors.

Orthodontists and their staffs must be reminded constantly, through appropriate chart designation, of patients who have orthognathic treatment plans. These patients often are subject to increased anxiety and have extra questions that need to be addressed to maintain their confidence and trust. At the presurgical consultation (step 12), the orthodontist and the surgeon must listen to the patient and determine the patient's physical, dental, and emotional readiness for surgery.[17,28,29,88]

The surgeon should present a clear review of the surgical procedure and the risks of surgery. The surgeon and the orthodontist must remember that most orthognathic patients have much to learn about their options, the recommended procedures, and the incumbent risks. The current trend to have a "one-step consultation" for orthodontic patients generally does not apply to orthognathic patients. One must respect the individual patient's "learning curve" requirements and be supportive by providing needed information and patience.

Several authors have done numerous studies assessing patients' responses to current orthosurgical treatment modalities.[17,28,29,96,98,99] A thorough review of their work is necessary to help orthodontists and their staff appreciate the range of feelings that orthognathic patients report before and after the surgical procedure. Table 25-6 describes the psychological considerations during the various treatment steps for a patient who is having jaw surgery.

Step 17: Treatment Experience. Step 17 is seldom incorporated in the routine policy sequence of private orthodontic and surgical practices. To gain the most from this step, all team members should review postsurgical records and discuss the positive and negative aspects of the overall treatment plan, the sequence of treatment, and provider interaction. Each completed case provides an opportunity for providers to consider feedback from one another and the patient. This step is the most powerful continuing education program in which a practitioner can participate. Having each orthognathic patient complete a posttreatment questionnaire also provides additional feedback and is an integral part of practice maturation.

APPLIED CONCEPTS FOR SPECIFIC TYPES OF CASES

Certain concepts that have been discussed in this chapter are integrated and applied to case types previously introduced in the differential diagnosis section. A summary of the concepts that are fundamental to consistent excellence in the management of skeletal disharmonies is as follows:

- *Treatment goals*: These are defined and agreed on in principle by the providers (see Box 25-1).
- Technique advancements: *These are used to enhance the safety of all orthognathic procedures.*[26,52,55,100,101]
- *Current capacity to alter dentofacial structures:* Because the potential degree of change is so great, the responsibility of the surgeon and the orthodontist in planning treatment also is great. Psychosocial and emotional balance may be at risk.[96]
- *Differential diagnosis process:* The differential diagnosis process generates a problem list and treatment planning options. The so-called *textbook ideal result* should be considered and discussed with all patients; however, not all patients have the resources for state-of-the-art treatment.
- *Treatment planning:* Treatment planning therefore creates alternatives. The *good, better, best*, approach to patient education yields understanding and trust.
- *Borderline cases:* Borderline cases (e.g., Class II with moderate lower jaw deficiency) can benefit from therapeutic diagnosis with initial leveling and alignment. Facial balance then can be assessed with the mandible postured forward. Computer and video imaging also can be used to teach patients about their options and potential outcomes.[73,102]
- *Standardized sequencing:* Following the 17 steps presented in Box 25-2 ensures a well-educated patient and a well-prepared treatment team.

An important part of orthognathic treatment planning involves surgical prediction. Hard tissue changes are easy to predict; however, soft tissue changes are less predictable (see Chapter 2). In Table 25-7, a variety of general guidelines are used to predict soft tissue changes in the lateral cephalometric view. However, with current surgical treatments, the most difficult soft tissue predictions to make are those that deal with changes in the frontal view. The patients in Figures 25-18 and 25-20 illustrate the outcome of treatment using the concepts described in this chapter.

The patient in Figure 25-21 has a classic skeletal Class II mandibular deficiency type I, low mandibular plane angle, condition (see template assessment in Figure 25-21, *B*). The patient in Figure 25-23 has a classic skeletal Class II mandibular deficiency type III, high mandibular plane angle (see template assessment in Figure 25-23, *B*).

Figures 25-25 and 25-26 show the treatment outcomes of three types of Class III skeletal mandibular excess. The patient in Figure 25-25 represents a classic patient whose skeletal problem can be described as Class III mandibular excess type II (see the template superimposition in Figure 25-25, *B*). Complete surgical correction of the mandibular excess depended on lower incisor decompensation from pretreatment incisor to mandibular plane angle of 77 degrees to presurgical angulation of 89 degrees.

The patient in Figure 25-26 demonstrates a classic example of mandibular excess type III (high mandibular

TABLE 25-6 Psychological Considerations in Clinical Interaction

Treatment Stage	Steps in Psychological Management
Initial assessment	Explore motives for treatment and expectations from treatment in detail. Why treatment? Why now instead of last or next year? Consider using an auxiliary with a warm personality to do at least part of the interview. Patients often are intimidated by the doctor and may not reveal their true concerns. Be careful not to create unrealistic expectations: it is better not to discuss the specifics of treatment procedures before the diagnostic workup has been completed, but a broad outline including the possibility of surgery should be presented.
Orthodontic consultation	The spouse, a family member, or a close friend should attend if at all possible, but be careful about invasion of patient's privacy. Begin with a discussion of the patient's problems; be sure doctor and patient agree as to what is most important; then describe how the problems might be solved, beginning with the most important problem and presenting the alternatives. Encourage—indeed, insist on—an early appointment with the surgeon if surgical treatment may be needed.
Surgical consultation	Review patient's records with same general approach as the orthodontist, emphasizing the problems and their possible solutions. Discuss the functional and aesthetic benefits of surgery in that order. To tell patients they will have functional benefits and aesthetic changes is better than the reverse. Functional changes nearly always are appreciated; aesthetic changes may not be. Provide more detail about the surgical experience, to the extent the patient has questions, but keep the discussion relatively general. Many details can wait until just before surgery (some patients may want a complete discussion). Consider using patient education materials at this stage, such as booklets, video cassettes, and videodisc. Offer to help with insurance preauthorization.
Presurgical treatment	Evaluate the patient's personality characteristics and psychological stability in more detail. Focus on neuroticism, degree of external locus of control, introversion in males, mood states (particularly depression and current major life events), and tendency for patient to be a vigilant coper.
Immediate surgery	Review the planned surgery in detail, but take the patient's psychological profile into account. Patients who expect the worst are more likely to experience it. Discuss with family members and close friends the importance of their psychological and emotional support postoperatively. Be sure significant others are prepared for changes in the patient's facial appearance so that they do not express shock or dismay.
Immediate postoperative period	Expect a period of mood swings and negative emotions, which usually peak at about 2 weeks. Reassure the patient, family, and friends that these emotions are normal and will soon disappear. A visit from the orthodontist and perhaps flowers or a care package of easy-to-eat foods keep the patient from feeling forgotten.
Postoperative orthodontics	Negative emotions and mood swings are more likely to be seen by the orthodontist in patients who return for finishing orthodontics. Reassurance and psychological support may be needed. Remember that a decrease in satisfaction and facial body image occurs if active treatment takes more than 6 months postoperatively. If treatment has not been completed by this time, progress should be reviewed with the patient and an anticipated completion date should be discussed.

From Kiyak HA, Bell R: Psychosocial considerations in surgery and orthodontics. In Proffit WR, White RP, editors: *Surgical orthodontic treatment*, St Louis, 1990, Mosby.

plane with open bite). Generally, patients with high mandibular plane angles and open bites require a maxillary Le Fort procedure with impaction and a mandibular procedure. Maxillary and mandibular procedures were performed on this patient. The patient in Figure 25-33 illustrates a well-treated patient who was not fully satisfied with her treatment (see Figure 25-33, *F*). Notice the improved response to treatment, using more current techniques of rigid fixation, in the patient who had a similar complicated skeletal problem (Figure 25-34).

OPTIMIZING STABILITY

Of the treatment goals discussed in the chapter introduction, orthodontists and surgeons are alike in their quest to recommend and perform procedures that give their patients lasting stability.[90,103–106] The stability of orthognathic procedures has been one of the most studied aspects of the techniques in use.[26,60,103,107,108]

Stability is a key goal of orthodontic treatment and orthognathic treatment; lack of stability is considered a

TABLE 25-7 **Current Concepts of Facial Growth**

Treatment	Soft Tissue Change	Notes
Anteroposterior movement of incisors: maxillary or mandibular, forward or back, surgical or orthodontic	60% to 70% of incisor movement Minimal unless jaw rotates	1–5
Vertical movement of incisors	Soft tissue: chin 1:1 with bone; lower lip 60% to 70% with incisor	6
Mandibular advancement	Nose: slight elevation of tip	7, 8
Maxillary advancement	Base of upper lip: 20% of point A Upper lip: 60% of incisor protraction, shortens 1 to 2 mm	
Mandibular setback	Chin: 1:1 Lip: 60%	5
Maxillary setback	Nose: no effect Base of upper lip: 20% of point A Upper lip: 60% of incisor Advancement of lower lip: variable, may move back	3
Mandibular setback plus maxillary advancement	Changes similar to a combination of the two procedures separately	
Maxillary superior repositioning	Nose: usually no effect Upper lip: shortens 1 to 2 mm Lower lip: rotates 1:1 with mandible	7
Mandibular advancement plus maxillary superior repositioning	Chin: 1:1 Lower lip: 70% of incisor Upper lip: shortens 1 to 2 mm 80% of any incisor advancement Nose: slight elevation of tip	
Mandibular inferior border repositioning	Soft tissue forward: 60% to 70% bone Chin: Up—1:1 with bone Back—50% bone Laterally—60% bone Down—?	

Data from Jensen AC, Sinclair PM, Wolford IM: Soft tissue changes associated with double-jaw surgery, *Am J Orthod Dentofac Orthop* 101(3):266, 1992.

1. Little difference occurred with surgery or orthodontics.
2. If both upper and lower incisors are retracted (bimaxillary protrusion), lip movement stops when lips come into contact.
3. Lip shortens 1 to 2 mm with vestibular incision (more if surgical technique is poor).
4. Lip rotates with mandible 1:1.
5. If face height increases, lip may uncurl and lengthen.
6. If lip uncurls, it will go forward less.
7. Nose change is usually temporary.
8. Less soft-tissue change occurs after cleft lip repair.

complication, particularly as it relates to the surgical aspect of the correction. To discuss the general concept of stability, one must consider several factors necessary to achieve stability[86] (see Chapter 27):

Orthodontic Considerations

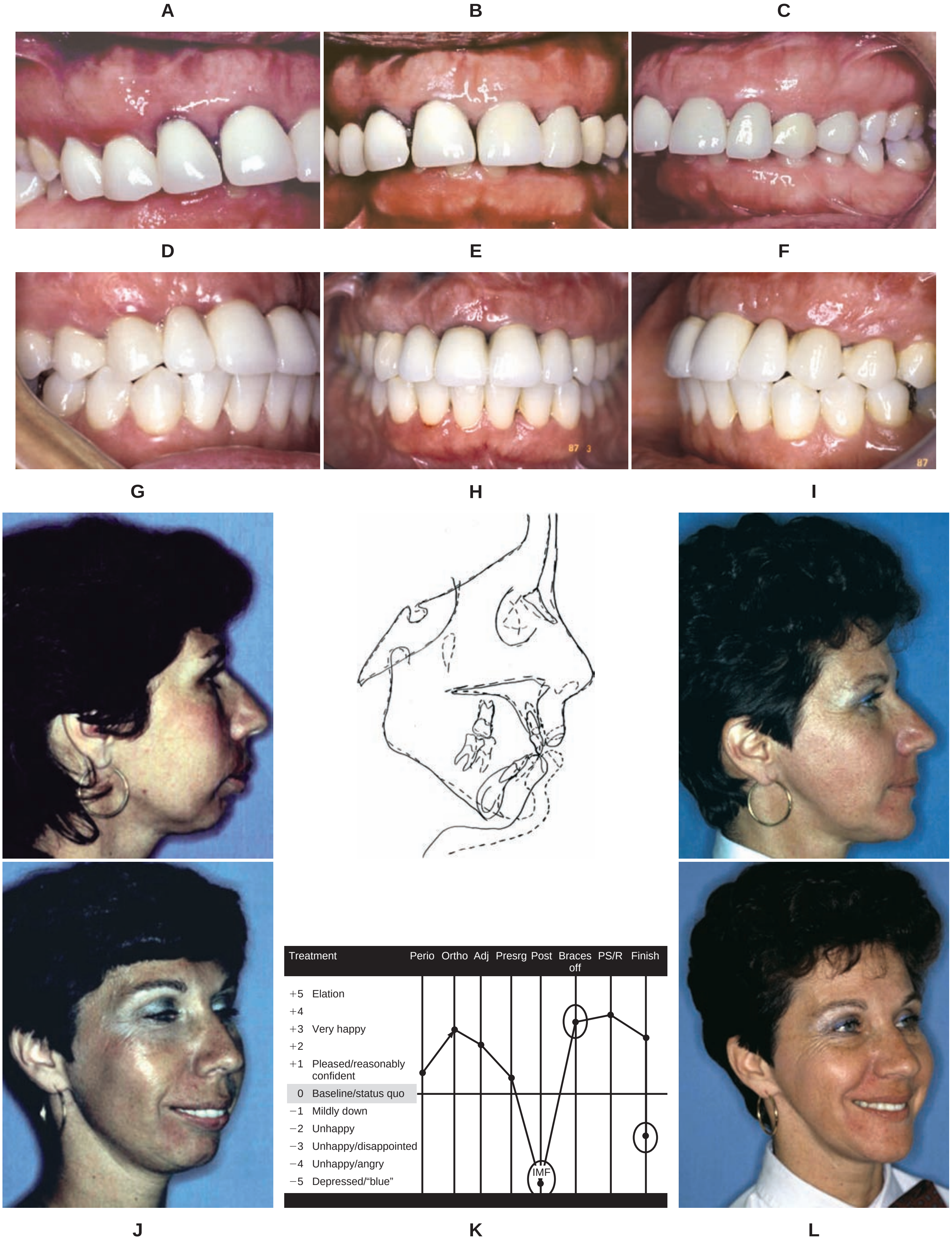
1. Differential diagnosis[109]
2. Growth factors and the timing of the referral[12,105,110,111]
3. TMJ stability when planning the treatment
    - Centric relation–habitual occlusion discrepancies[10]
    - Asymmetric growers
4. Dental stability
    - Crown-to-root ratio is important (periodontal health must be maintained).
    - Temporary crowns can be a source of instability during intradental fixation.
5. Presurgical orthodontic preparation to reduce dental compensations

Stability

- Orthodontic considerations
- Dental stability
- Presurgical orthodontic treatment to eliminate dental compensations
- Surgical considerations

Surgical Considerations

1. Treatment plan correlated with diagnosis
    - Surgery on which jaw
    - Single- or double-jaw procedures, especially for open bite
2. Design of osteotomy
    - Maintenance of blood supply and achievement of surgical objectives[41,44]
3. Type of fixation
    - Dental, skeletal, rigid, semirigid, or combination


A
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Presrg
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PS/R
Finish
+5 Elation
+4
+3 Very happy
+2
+1 Pleased/reasonably confident
0 Baseline/status quo
−1 Mildly down
−2 Unhappy
−3 Unhappy/disappointed
−4 Unhappy/angry
−5 Depressed/"blue"
IMF
J
K
L

FIGURE 25-33 **A–C,** Pretreatment intraoral photographs. **D–F,** Posttreatment photographs. **G,** Pretreatment profile. **H,** Cephalometric superimposition; *solid line* indicates pretreatment contours, and *dashed line* indicates results after treatment. Treatment included the following:
Le Fort osteotomy with 5 mm of impaction and movement of A point 2 mm distally
Mandibular autorotation and advancement; B point came forward 13 mm
Vertical reduction and advancement genioplasty; pogonion came forward 16 mm
I, Posttreatment profile. **J,** Pretreatment three-quarter view, smiling. **K,** Graph showing the patient's attitude changes during the program of state-of-the-art comprehensive dentistry. Her posttreatment negative feelings were related to residual temporomandibular joint discomfort and to the belief that she had not been informed fully about some of the downsides of the multidisciplinary treatment. **L,** Posttreatment three-quarter view, smiling. *(Surgery by R. Kallal, Chicago, IL.)*

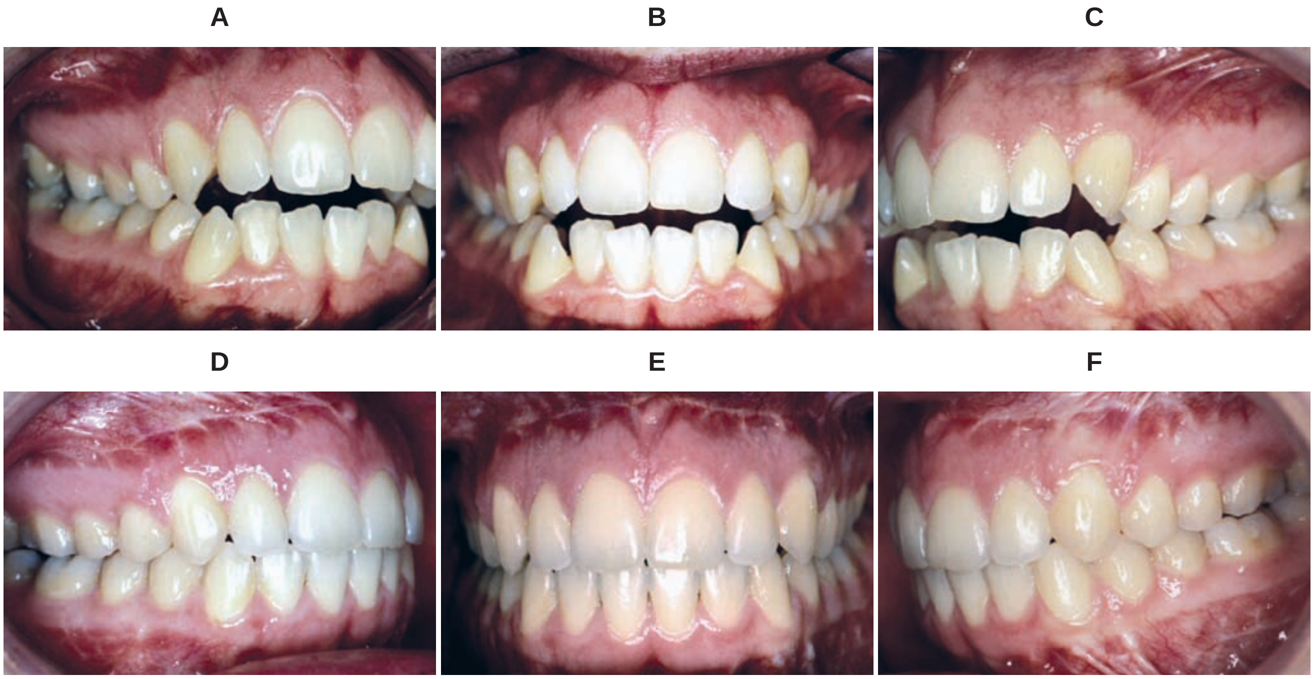


FIGURE 25-34 **A–C,** Pretreatment intraoral photographs. **D–F,** Posttreatment photographs.

Continued

4. Muscles of mastication and blood supply
   - In a sagittal split of the mandible, one is advised not to strip the pterygomasseteric attachment to avoid ischemia, delayed healing, and unusual nerve complications.
5. Type of mandibular rotation
   - Downward, backward movement is considered more stable than upward, forward movement.
   - Recent research has verified that occlusal plane change surgery and counterclockwise mandibular rotation can be very stable.[26]
6. The stability decreases as the magnitude of surgical correction increases, especially in the following
   - Maxillary vertical deficiencies
   - Mandibular horizontal deficiencies
7. Stability of the condylar position

   Stable condylar position applies to presurgical assessment, surgical control of the proximal segment, and the patient's postsurgical adaptation to the new neuromuscular and functional environment; also, Gunson and others[54] have described the condition of idiopathic female condylar resorption, which may be responsible for late condylar changes (e.g., cheerleader's syndrome, avascular necrosis, or condylolysis). These findings led the authors to hypothesize that some women are prone to condylar resorption that occurs following increased joint load and may be related to oral contraceptive pill use, which is well tolerated by most women and girls (Figure 25-35).
8. Neuromuscular adaptation

   The surgical procedures that change the skeletal structures also change long-standing neuromuscular patterns of the stomatognathic system; achieving a balance or an equilibrium of the skeletal structures, dental structures, and muscles is the ultimate

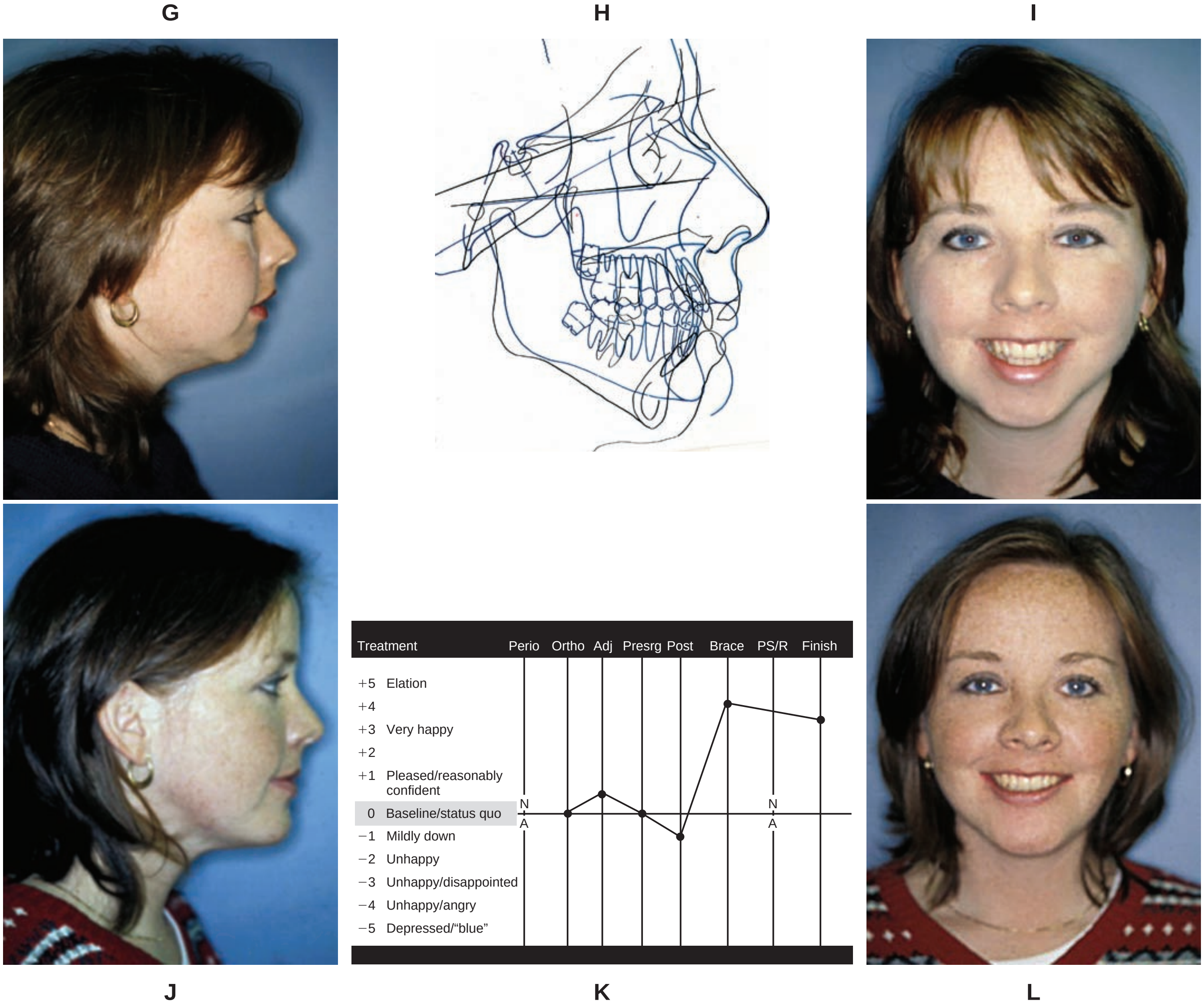


FIGURE 25-34, cont'd **G,** Pretreatment profile. **H,** Bolton template-guided diagnosis. Treatment included the following:

Presurgical upper and lower arch alignment to prepare for skeletal correction indicated in Figure 25-34, *H.*
Le Fort 1 osteotomy with rigid fixation—anterior raised 5 mm; posterior raised 2 mm
Mandibular advancement via bilateral sagittal split osteotomies with rigid fixation—advanced 10 mm
Alloplastic chin implant—6 mm implant placed

I, Pretreatment facial smile. **J,** Posttreatment file. **K,** Chart showing patient's attitude changes during the interdisciplinary treatment plan. Note the differences in charts depicted in Figures 25-33, *K*, and 25-34, *K*, reflecting posttreatment "quality of life improvement" as a result of rigid fixation rather than IMF used for the patient in Figure 25-33.

L, Posttreatment facial smile. *(Surgery by R. Kallal, Chicago, IL.)*

biologic challenge for the orthognathic team. Although the procedures performed today are based scientifically on a variety of working hypotheses, the relapse problems that still occur are reminders that some of the treatment provided may have empirical components.

Planning treatment for orthognathic cases can aid the stability of the treatment outcome through the following:

1. Proper *differential diagnosis* of patients who would most benefit from combined therapy[109,112]: The classic example is the Class III grower. The orthodontist must determine through differential diagnostic studies and growth forecasting whether this patient has a mandibular excess condition. In borderline situations, an early phase of treatment can test, through therapeutic diagnosis, for skeletal modifiability and functional shifts. In other cases, surgery clearly is needed.

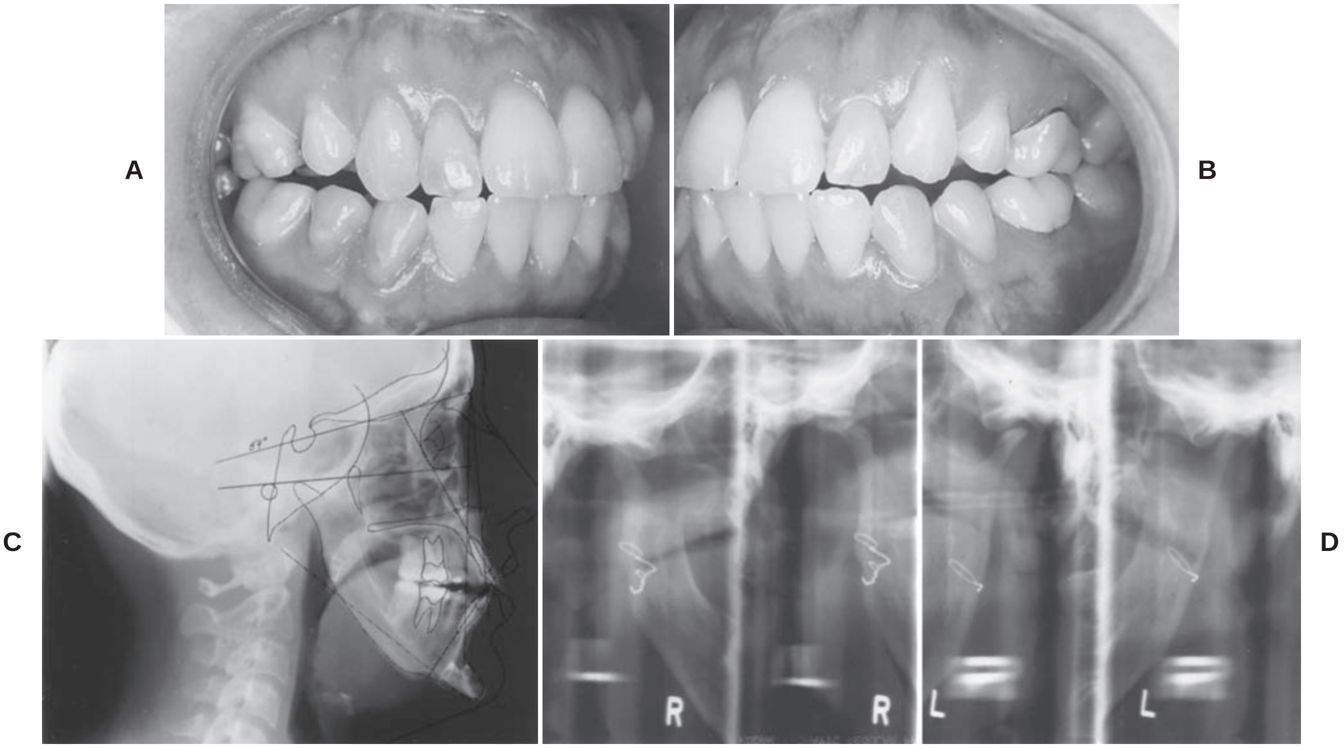


FIGURE 25-35 **A,** Right posterior occlusion in a woman (age 35 years 10 months) after two orthodontic treatments and two separate orthognathic procedures. **B,** Lateral posterior occlusion after two orthodontic treatments and two separate orthognathic procedures. **C,** Lateral cephalogram after two separate orthodontic and surgical treatments. Note the lack of incisal contact. Patient stated that the "open bite is progressively getting worse." **D,** The right condyle shows degenerative changes, and the left condyle shows degenerative changes similar to those described by Arnett and Tamborello.[111a]

However, the orthodontist still may resolve the maxillary transverse deficiency and the anterior alignment during phase I while anticipating the second phase of braces at ages 16 to 23 and surgery when facial growth is complete. The orthodontist plays a major role in guiding these cases to completion. For example, orthodontic heroic efforts to treat skeletal Class II problems nonsurgically for a protracted period in camouflage therapy may overcompensate the teeth and interfere with the ultimate need to provide corrective surgery later. "The efficacy data of 34 Class II subjects who underwent surgical-orthodontic treatment with mandibular advancement and rigid fixation demonstrated the presurgical orthodontic treatment often does not fully decompensate the incisors, which limits the surgical outcome."[109]

This is also true of moderate to severe mandibular deficiency, high mandibular plane angle (downward and backward) growth patterns. Early introduction of the concept of combined therapy (orthodontics and surgery) conditions parents to the necessity of surgical correction and begins the psychological preparation of the patient. One must take care to use terminology that does not frighten or stigmatize young patients. The authors recommend conducting preliminary surgical consultations with the parents only for patients under age 16. This allows the parents to assimilate the surgical information and make the final decision as to the desirability of including their adolescent in the surgical discussion at the current time.

2. *Growth factors and the timing of the referral*: Orthodontists know that posttreatment growth is a destabilizing factor in orthodontic treatment results. In a study by the author, 42 of 100 adult patients (42%) who required retreatment did so because of growth changes that moderately or severely altered the original orthodontic correction.[40]

   If the differential growth is minimal, the occlusal change can be handled by 4 to 8 months of orthodontic retreatment. However, if growth undermines an orthodontic correction, the patient may not easily accept retreatment by means of surgery.

To avoid growth-induced complications, one should consider the following guidelines:

a. For moderate and severe Class III mandibular excess patients, surgery should be delayed until standardized cephalograms demonstrate completion of mandibular growth. In boys and young men, this could be as late as 22 to 24 years of age.
b. For patients with asymmetry and unilateral hypertrophy, surgery should be delayed until bone scans

demonstrate cessation of growth activity of the hypertrophic condyle.

c. In selected patients with excessive vertical growth (Class I and Class II), the maxillary Le Fort procedure can be considered before growth is complete when psychosocial factors dictate.[96] The effect of this procedure on the future growth of the nasal cartilage is not understood fully. However, a risk exists that premature double-jaw surgery for mandibular deficiency, high mandibular plane angle Type III patients will be unstable if the mandible persists in a downward and backward growth mode and reopens the bite.

d. For patients with maxillary transverse deficiency, orthopedic expansion may be effective for most girls up to 14 years of age and for many boys up to 16 years of age. Successful orthopedic expansions have been reported in both genders at older ages, especially with surgical assistance. The predictability of nonsurgical orthopedic success declines as the patient's age increases.[28,29,107,113]

e. Psychosocial needs may supersede growth factors when the patient has a severe growth imbalance. Self-esteem considerations during adolescence deserve concern, and two-stage sequential surgery may be desirable for patients whose psychological and social development is affected by their jaw growth imbalance[96,105,106] (Figure 25-36).

f. The timing of the referral to the maxillofacial surgeon and the initial patient education process are important responsibilities of the orthodontist. The orthodontist should try to determine the patient's level of awareness about the growth imbalance. If a patient is unaware that the condition may require surgical adjuncts, the education process may take longer and require more than one consultation with the orthodontist to create sufficient understanding to pursue the consultation.

3. *TMJ stability*: The orthodontic literature emphasizes the importance of planning treatment based on a reproducible condylar-fossa relationship.[114,115]

This concept is all the more true when diagnosing and planning treatment for orthognathic patients. The orthodontist's skill in diagnosing and documenting functional shift problems in the occlusion is important. Without such skill, a mandibular functional shift may make a case look better than it is, causing a treatment plan to fail because of undertreatment; or at the other extreme, it may make a case look worse than it is (e.g., Class III skeletal problem amplified by a functional shift) because of functional forward shift, causing treatment plan failure by overtreatment (i.e., insisting on surgery when the case can be managed with conventional treatment only) (see Figure 25-39).

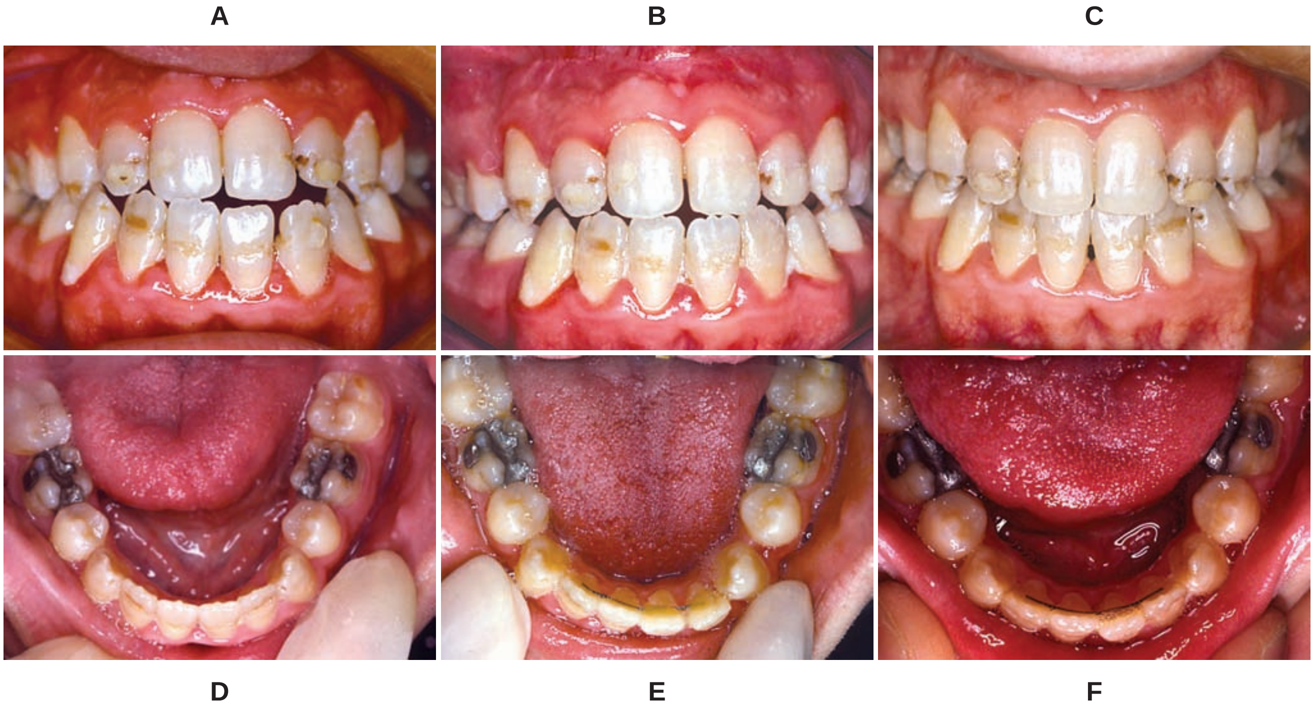


FIGURE 25-36 **A,** Anterior occlusion after braces and maxillary and mandibular surgery on a 14.5-year-old Class III patient. **B,** Anterior occlusion after 1.5 years of retention. Note lower incisor displacement. **C,** Anterior occlusion after phase II orthodontics; patient refused additional jaw surgery. **D,** Lower incisors after braces and maxillary and mandibular surgery on a 14.5-year-old patient. **E,** Lower incisor displacement after 1.5 years of retention with bonded retainer. Note tongue size. **F,** Lower incisors after phase II orthodontics and tongue reduction.

The time to diagnose mandibular shifts is before treatment is initiated and is accomplished through the use of superior repositioning deprogramming splints, leaf gauge condylar seating, or careful manipulation of the mandible.[10] If such discrepancies are not detected before appliance placement but show up during treatment, the clinician has an obligation to document and inform the patient of the diagnostic data arising during treatment and advise the patient of any recommended change in the plan. The patient then must decide whether to pursue or reject the surgical plan. Undetected functional shifts in maxillary vertical excess and mandibular deficiency cases can lead to a treatment plan that calls for Le Fort impaction only. The operating room, with the patient under general anesthesia, is not the place for the surgeon to revise the treatment plan from a one-jaw procedure to a double-jaw procedure. Clarification and documentation of centric relation mandibular position should be done before the treatment plan is finalized.[13,26,116]

Other TMJ stability concerns are addressed in the Risks section of this chapter.

4. *Dental unit stability*: One aspect of dental instability may be an unfavorable crown-to-root ratio, which occurs following bone loss from periodontal disease or as a result of short roots, whether genetic or acquired. The orthodontist should be able to detect tooth mobility problems and advise the surgeon of the need for skeletal rather than interdental fixation.

   Another form of dental instability features temporary crowns cemented as part of a periorestorative program. Brackets break easily from these crowns, and the crowns dislodge easily from the teeth (Figure 25-37, *D, E*). For these reasons, interdental fixation in a patient with temporary crowns is not advisable.
5. *Presurgical orthodontic preparation*: Arch leveling should be inclusive of second molars. In mandibular excess cases, the upper second molar frequently is supraerupted (Figure 25-38), and in mandibular deficiency cases, the lower second molar may be supraerupted. These distal teeth, if not level vertically, can interfere with proper occlusal seating at the time of surgery, creating condylar distraction and instability. In addition, the lower incisors may be supraerupted in a skeletal Class II or III problem and require leveling with intrusion to prepare for the surgical phase. Certain surgical treatment plans may call for segmental intrusion, and the arch may require segmental leveling to satisfy the stability and aesthetic requirements of the case. Continuous archwires may cause instability through unwanted incisor extrusion (in an open bite case), causing less skeletal correction of the open bite and dental relapse.

As treatments are planned, the nine key responsibilities of the surgeon to maximize the stability of the orthognathic outcome (presented earlier in this section of the chapter) require periodic review with the surgeon.

RISKS OF ORTHODONTIC/ ORTHOGNATHIC SURGERY

The risks to which patients are exposed during routine orthodontic therapy are minimal compared with the complications that may occur during orthognathic procedures.[117] Practicing orthodontists must understand all the differential diagnostic considerations of the patient with skeletal imbalances, and should also be well aware of the risk factors associated with the orthognathic procedures recommended. As the range of corrective procedures has widened, the reported negative sequelae have increased.

In the previous section of this chapter, the undesirable risk factors of instability were discussed. This section focuses on a variety of other complications that have been associated with orthognathic procedures (i.e., risk management). Complications are not common in orthognathic surgery but they do occur. Several studies have shown complication rates.[46,47,70,118] Box 25-7 summarizes the complications recorded in the studies referenced.

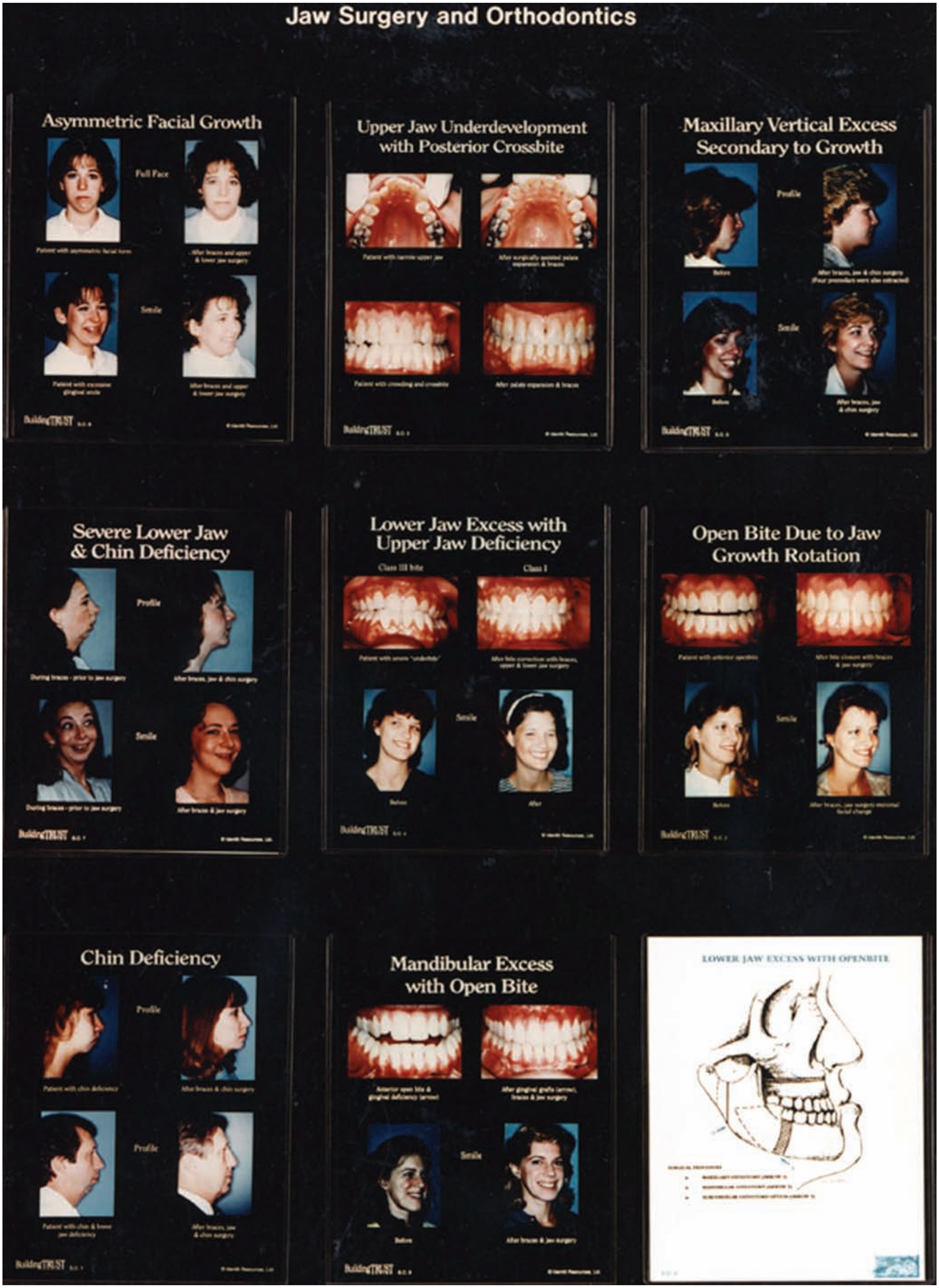
There are a broad range of complications related to orthognathics that can be divided into the following categories: A. physical well-being; B. stomatognathic function; C. emotional well-being; and D. oral health sequelae.

A. Physical Well-being
   1. Excessive blood loss[70,118,119]
   2. Neurologic injury (anesthesia, paresthesia)[119,120]

BOX 25-7 Common Complications in Orthodontic/Orthognathic Surgery

Most Common Complications with Maxillary Surgery[21]
- Nausea or vomiting—40.08%
- Infection rate (acute or chronic)—7.4%
- Anatomic complication including deviated nasal septum—2.65%, nonunion at osteotomy gap—1.0%
- Extensive bleeding requiring blood transfusion—11%
- Ischemic complication causing aseptic necrosis of the alveolus—0.2%, gingival recession—0.8%
- Insufficient fixation—0.5% (most common in patients with clefts, craniofacial dysplasias, or vascular anomalies)

Most Common Complications with Mandibular Surgery
- Neurosensory deficit mild—32%
- Disturbing—3%
- Infection rate—7.4%



Jaw Surgery and Orthodontics

Asymmetric Facial Growth

Full Face

Patient with asymmetric facial form

After braces and upper & lower jaw surgery

Smile

Patient with excessive gingival smile

After braces and upper & lower jaw surgery

BuildingTRUST

Upper Jaw Underdevelopment with Posterior Crossbite

Patient with narrow upper jaw

After surgically assisted palate expansion & braces

Patient with crowding and crossbite

After palate expansion & braces

BuildingTRUST

Maxillary Vertical Excess Secondary to Growth

Profile

Before

After braces, jaw & chin surgery
(Four premolars were also extracted)

Smile

Before

After braces, jaw & chin surgery

BuildingTRUST

Severe Lower Jaw & Chin Deficiency

Profile

During braces - prior to jaw surgery

After braces, jaw & chin surgery

Smile

During braces - prior to jaw surgery

After braces & jaw surgery

BuildingTRUST

Lower Jaw Excess with Upper Jaw Deficiency

Class III bite

Class I

Patient with severe "underbite"

After bite correction with braces, upper & lower jaw surgery

Smile

Before

After

BuildingTRUST

Open Bite Due to Jaw Growth Rotation

Patient with anterior openbite

After bite closure with braces & jaw surgery

Smile

Before

After braces, jaw surgery; minimal facial change

BuildingTRUST

Chin Deficiency

Profile

Patient with chin deficiency

After braces & chin surgery

Profile

Patient with chin & lower jaw deficiency

After braces, jaw & chin surgery

BuildingTRUST

Mandibular Excess with Open Bite

Anterior open bite & gingival deficiency (arrow)

After gingival grafts (arrow), braces & jaw surgery

Smile

Before

After braces & jaw surgery

BuildingTRUST

LOWER JAW EXCESS WITH OPENBITE

FIGURE 25-37 **A,** Postsurgical occlusion after mandibular distraction. **B,** Panoramic radiograph after mandibular distraction to correct Class II. Note damaged root of No. 19 and No. 30 caused by faulty surgical technique. **C,** Panoramic radiograph with abscessed No. 19 and No. 30 removed; planned for bone graft and implant at No. 19 and No. 30 space in future. **D, E,** Postsurgical and immediate postfixation right and left posterior occlusion, showing the loss of four brackets from plastic temporary crowns (*arrows*). Also note the surgical overcorrection of a severe skeletal mandibular deficiency (the treatment outcome in the case is shown in Figure 25-33).

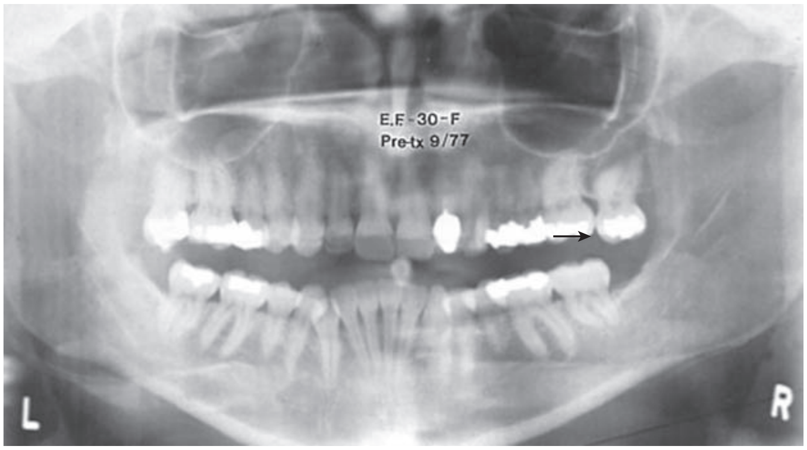


FIGURE 25-38 Pretreatment panoral film shows several problems arising from mandibular excess (this patient's condition was shown in Figure 25-25). Note the supererupted right second molar (*arrow*).

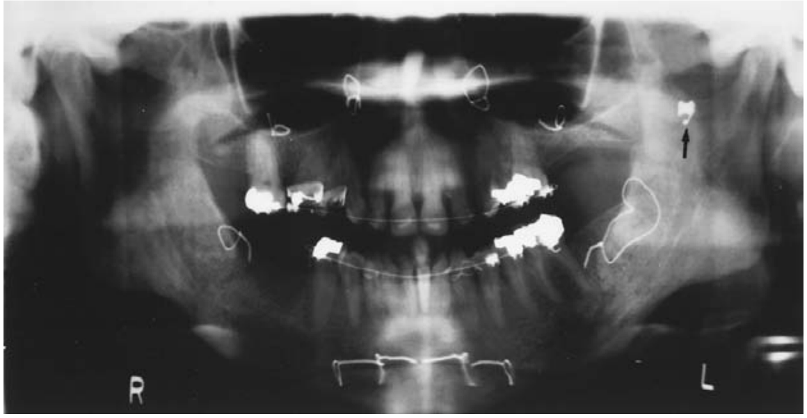


FIGURE 25-39 Postsurgical panoral film shows molar bracket (*arrow*) that broke off during surgery. The bracket has migrated to the coronoid notch.

   a. Hypoesthesia (decreased sensation)
   b. Hyperpathia (increased sensation)
   c. Dysesthesia (altered sensation that is painful)
3. Allergic reaction to anesthetic, antibiotic, or anti-inflammatory drugs
4. Postoperative infections[70,117,120,121]
   a. Surgical site
   b. Skeletal fixation wires
   c. Rigid fixation plates

   Current infection prevention techniques are discussed by Spaey and colleagues.[48] In addition, orthodontists can aid the surgeon in reducing potential iatrogenic incidence of nidi of infection by using soldered or slide-on surgical hooks, well-secured brackets, and stainless steel ligatures (not A-lastics because their force decays rapidly, and they are not radiopaque; if A-lastic ligatures inadvertently fall into the surgical site, they are difficult to locate and remove). Figure 25-39 shows the postsurgical migration of a molar bracket that broke off the left first molar during surgery. Fortunately, no infection developed.
5. Bone fractures (Figure 25-40)

   Reports exist in the literature of unfavorable surgical splits of the mandible, including buccal plate fracture associated with impacted third molar teeth that were extracted at the time of the mandibular osteotomy. When sagittal split procedures are planned for mandibular deficiency or mandibular excess, it is prudent to remove third molars 6 to 12 months before the

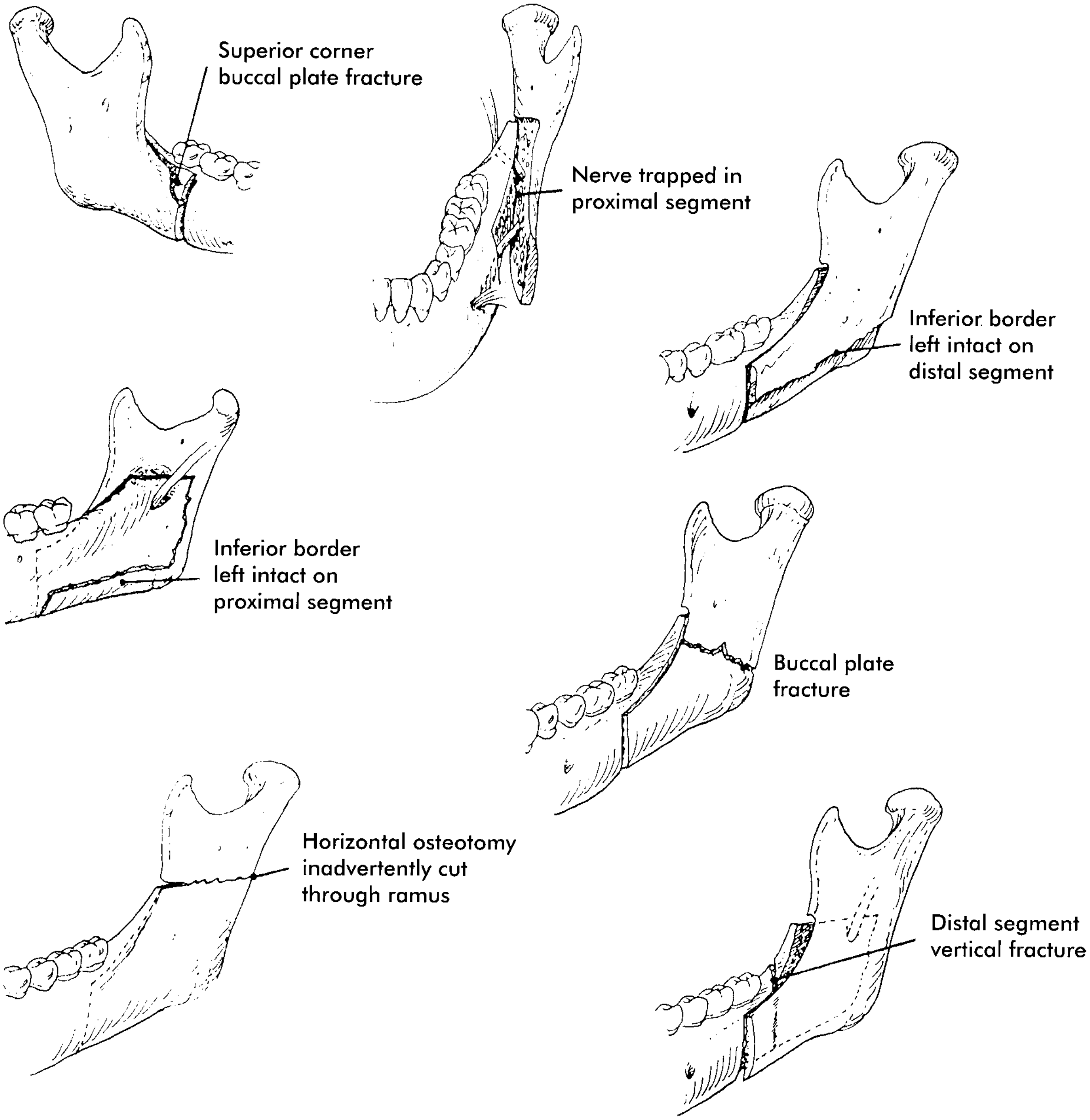

Superior corner buccal plate fracture
Nerve trapped in proximal segment
Inferior border left intact on distal segment
Inferior border left intact on proximal segment
Buccal plate fracture
Horizontal osteotomy inadvertently cut through ramus
Distal segment vertical fracture

FIGURE 25-40 Common types of unfavorable splits. *[From Sinn DP, Ghali GE: Management of intraoperative complications in orthognathic surgery,* Oral Maxillofac Clin North Am *2(4):872, 1990.]*

osteotomy to avoid the risk of unfavorable fractures. When unfavorable splits occur, the stability of the procedure is jeopardized and the likelihood of neuropathies and facial deformities is greater. If an unfavorable split occurs, the surgeon must decide whether to proceed with the surgery or repair the fracture and redo the surgery at a later time.

6. Delayed healing and nonhealing

   Delayed healing and nonhealing occur most often when unexpected microtrauma or macrotrauma occurs in the surgical and postsurgical periods. Intraoperative complications such as those discussed previously and including unfavorable splits in the sagittal split or unfavorable downfracture in the Le Fort osteotomy can result in incomplete bone healing. An inaccurate preoperative medical assessment (see Table 25-5) or postoperative surgical traumatic occlusion also can result in poor bone healing and fibrous unions.

7. Secondary surgery

   A small percentage of orthognathic patients must return to the operating room for secondary surgery because of unexpected surgical outcomes. Some return before release from the hospital after the first surgery; others return months or years later (Figure 25-41). The most common reasons for secondary surgery include the following:

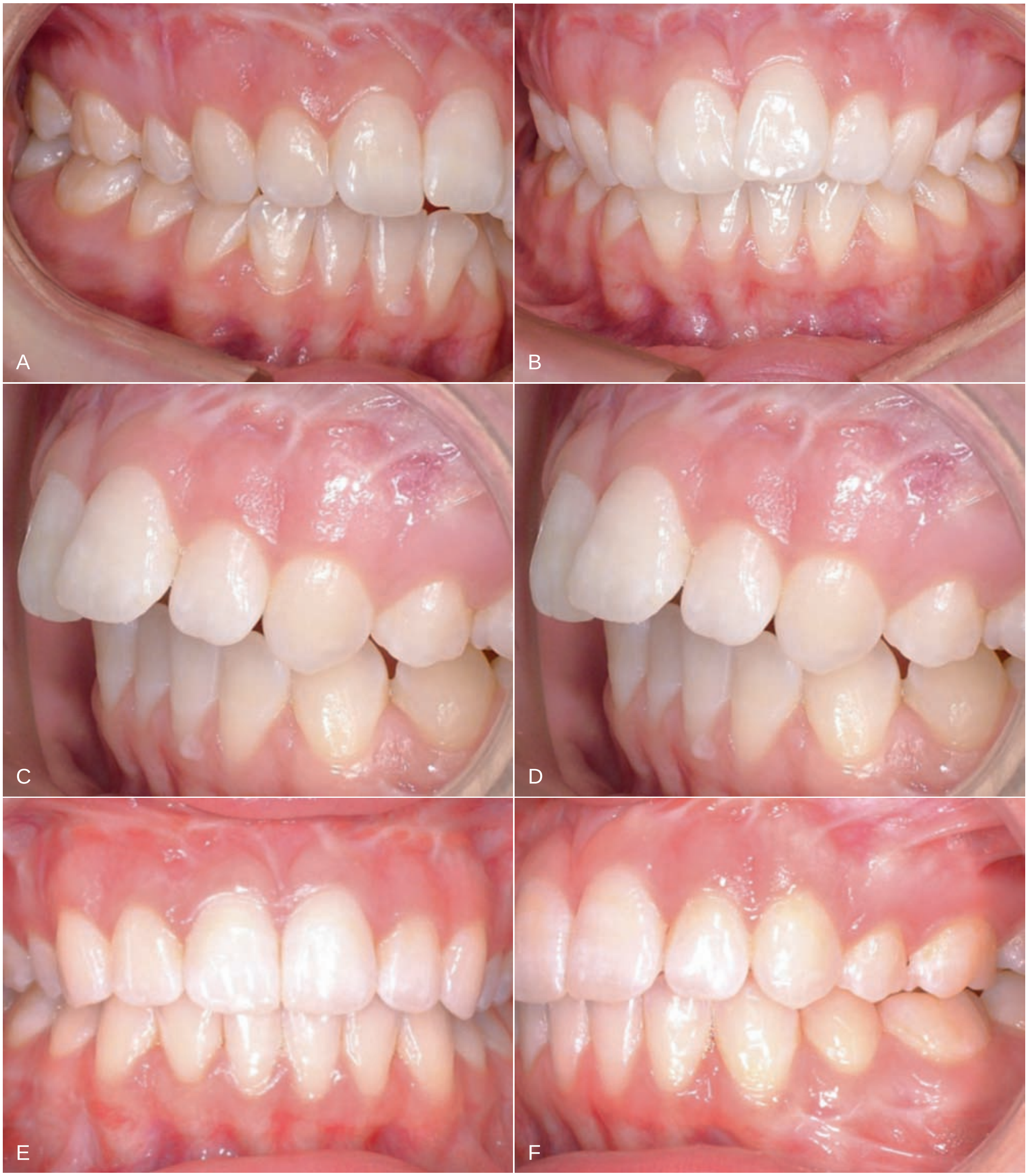


FIGURE 25-41 **A–C,** Intraoral photographs during evaluation for exposure to third orthodontic and surgical treatment plan. Instability resulted from previous treatment, which included orthodontics and four premolar extraction followed by double jaw surgery. Instability of initial surgical result and temporomandibular joint pain created a need for a second surgical procedure with the same orthodontist and surgeon. **D–F,** Intraoral photographs after orthodontic preparation and third surgical treatment with new orthodontist and surgeon. Due to previous dental instability, permanent, fixed retention was incorporated in her treatment.

Continued

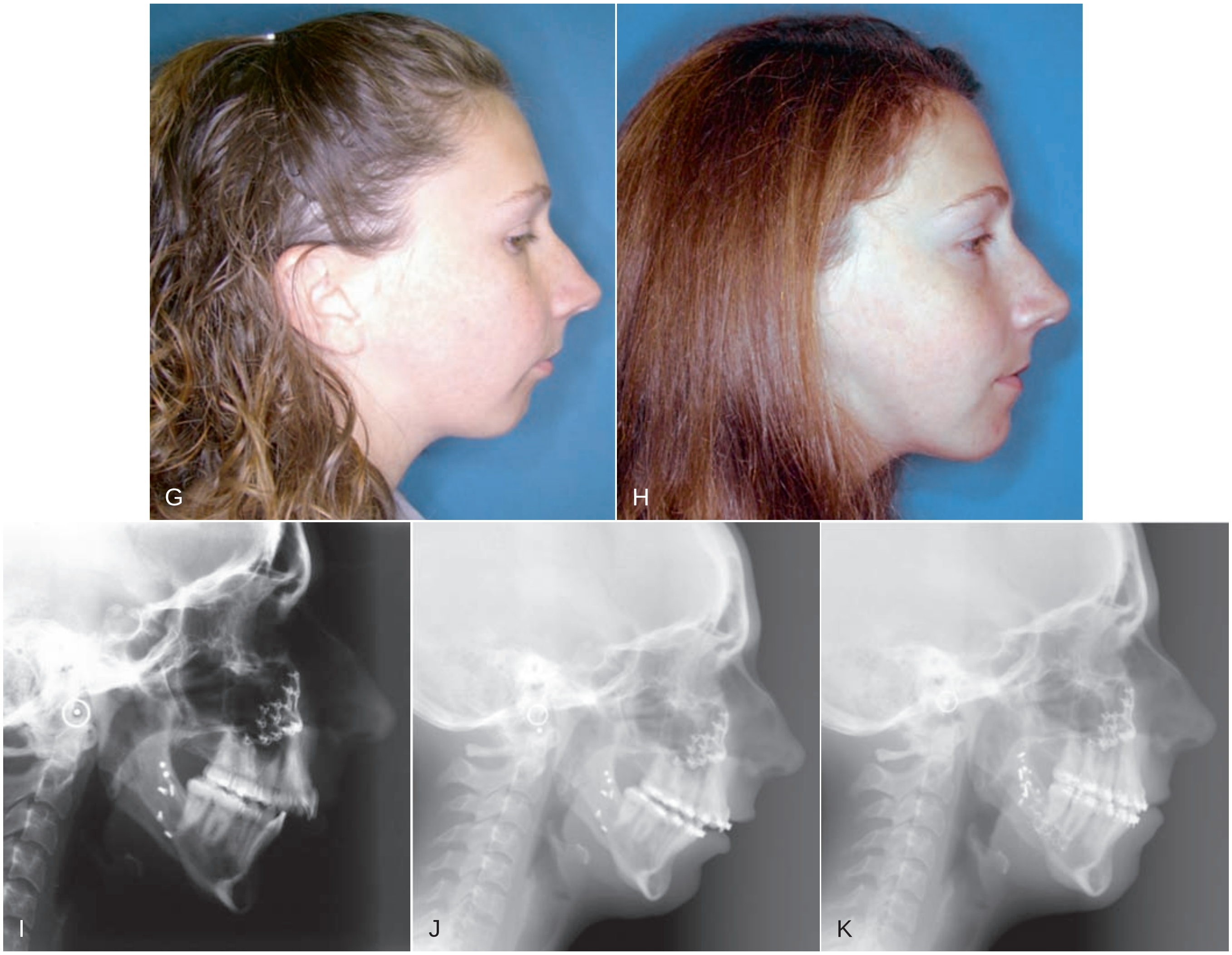


FIGURE 25-41, cont'd **G–H,** Profile photograph before and after surgery, respectively. **I–K,** Lateral cephalograms: initial, presurgical (after decompensation), and postsurgical, respectively. Vertical chin reduction and advancement were considered, but the patient declined this procedure.

- Early relapse
- Posthealing relapse
- Unfavorable split
- Patient dissatisfaction with the aesthetic result (in the early years of the Le Fort procedure, the maxilla was impacted beyond an aesthetic smile line in some patients)

Overimpaction of the maxilla can occur for several reasons:

- Removal of an excessive amount of bone from the lateral walls
- Presence of thin, concave maxillary bone that may collapse on loading
- Use of overly tight interosseous suspension wires that tend to pull the maxilla superiorly
- Excessive masticatory function that overrides the stability of the bony interfaces
- Lack of bony contact
- Inappropriate treatment planning

Correction of overimpaction cannot be achieved short of surgically repositioning the maxilla inferiorly and returning the dentoalveolar portion to its original position. This would require interpositional bone grafting and rigid internal fixation and possibly concomitant mandibular surgery.[121]

8. Sinus complications

Several authors who have studied postsurgical patients have found that a higher percentage than expected reported sinus problems after Le Fort procedures.[122,123] Other authors have indicated that postsurgical sinus disease is no greater than that in the general population.[115] Postsurgically, the maxillary sinus function may have been altered such that it interferes with proper drainage, causing sinus-type headaches, or sinuses may congest more frequently, causing interference with nasal breathing. Although this complication may seem relatively minor, it can have an adverse effect on the quality of life of patients who must deal with chronic sinus flare-ups.

B. Stomatognathic System Function

1. Decreased efficiency and discomfort during chewing

Two common causes of postsurgical occlusal inefficiency are the following:

- Posterior open bites caused by overseating of condyles during mandibular surgery
- Excessive superior positioning of the posterior maxilla, especially when posterior vertical stops are inadequate in the area of the osteotomy

2. Temporomandibular dysfunction, discomfort, and pain

Orthognathic surgery in some cases is justified because it has the potential to reduce temporomandibular dysfunction symptoms. Karabouta and Martis[124] reported that temporomandibular dysfunction symptoms declined from 40% to 11% of the sample. However, 4% of previously asymptomatic patients developed temporomandibular dysfunction symptoms after surgery. In another study Kerstens et al.[125] and Kim et al.[126] found a 66% reduction in temporomandibular dysfunction symptoms; they also found that 11.5% of preoperatively asymptomatic patients experienced symptoms after surgery. Many of these patients may have had latent temporomandibular dysfunction problems that were activated by the altered joint loading after jaw surgery. Management requires a team effort and appropriate care, depending on the nature of the problem.

3. Limitation in range of motion

A program of physical therapy is prescribed for most orthognathic patients shortly after the release of fixation. If mandibular hypomobility is present after jaw surgery, it could have an intracapsular or extracapsular cause. Intracapsular problems are characterized by a sharp pain localized in the TMJs. Extracapsular problems are characterized by less intense, dull pain that is generalized and diffuse and may or may not be aggravated by mandibular surgery; often the pain is alleviated by biting.[127]

A prospective study of 55 orthognathic patients by Aragon et al.[128] found that the maximal incisal opening (MIO) decreased in most of these patients after surgery. The percentage of MIO decrease depended on the surgery performed:

Procedure	**Percentage MIO reduction**
Sagittal split osteotomy (SSO)	29% (mean)
Vertical subcondylar osteotomy (VSO)	10% (mean)
Le Fort I	2% (mean)
Le Fort I and SSO	28% (mean)
Le Fort I and VSO	9% (mean)

C. Emotional well-being

1. Adaptation to Facial Appearance Change

Because orthognathic procedures can change facial appearance significantly, numerous studies have been done investigating patients' emotional response after surgery.* In the authors' experience, negative emotional responses seldom occur with single-jaw mandibular advancement or mandibular setback procedures because these procedures mainly affect the patient's profile, and therefore the patient does not observe these changes readily. Changes that occur with single-jaw Le Fort procedures or Le Fort procedures with mandibular advancement or setback alter the frontal facial appearance immediately, and the patient must adapt to the new look.[5]

2. Self-esteem changes caused by unexpected facial changes[17,28,29,32,88,89,129,130]

In Jacobson's study,[131] most patients (80%) said that orthodontic-orthognathic treatment influenced their lives positively, and 4% said that treatment had a negative influence on social activities (the remaining 16% were neutral about the impact of surgery on their lives). In their study of 55 patients, Kiyak et al.[28] found that at the 9-month postoperative interval, the patients' self-esteem had declined significantly from an early postsurgical period. The orthodontist and staff who follow these patients after surgery must be aware of the potential for emotional highs and lows during the postsurgical period. Having a psychologist available who is aware of the needs of orthognathic patients and who is able to intercept significant patient emotional problems is imperative.

3. Lack of preparation for changes in interpersonal relationships

As the surgical technology has improved to allow more stable, functional results, so too has the capacity to alter a person's appearance and identity. Most orthognathic patients are women between the ages of 20 and 40 years. Many are married and have husbands and young children. When this person returns home from the hospital after a Le Fort osteotomy and genioplasty, she is swollen and black and blue (bruised), and she may be in fixation with limited speech and eating capacities. If the immediate family members in the support group are not prepared fully for her to return looking so different, significant stress and disruption of normal family functions will result. As one patient in the study by Kiyak et al.[28] commented, "I would not recommend this surgery to anyone without counseling."

Patients who have had the surgery have many good ideas about ways to enhance the recovery process. Another patient in the study said the following:

> *Much more time is needed to prepare the patient with facts and information. I was unprepared for the bleeding and earaches, leaving the hospital so soon—less than 24 hours after surgery. I lost more weight than expected and really suffered psychologically and felt little support during the fixation period. Maybe the patients could be invited to form a mutual support group.*[122]

4. Depression

Postsurgical depression has received little attention in the orthognathic literature and only recently has been discussed as a legitimate complication of jaw surgery.[132] Generally, dentists are not trained properly to handle depression medically, even if it is likely to be a transitory state of mind for the orthognathic patient. However, the orthodontic members of the health care team have the duty to recognize the symptoms of depression, discuss them with the patient and family, refer the patient when necessary, and interact with the psychologist to aid in the patient's recovery. In addition, the orthodontist should try to be aware of other stressful events in the patient's life that may add to the anxiety level during the 2 to 3 years these patients are followed.

Although the current literature discusses the postsurgical sequelae of depression,[108,133–135] the authors' experience is that patients with rigid fixation show rapid psychological rebound and fewer signs of depression than patients of 5 to 10 years ago, whose jaw surgery required intermaxillary fixation for 6 to 10 weeks.

D. Oral Health Complications and Sequelae

1. Bone loss[136]

Although this complication is not reported frequently, the exacerbation of existing periodontitis is a potentially serious problem. Patients with mild, moderate, or advanced periodontal disease require strict supervision and management by a specialist before orthognathic procedures. Patients with moderate or advanced periodontal disease are at high risk for further

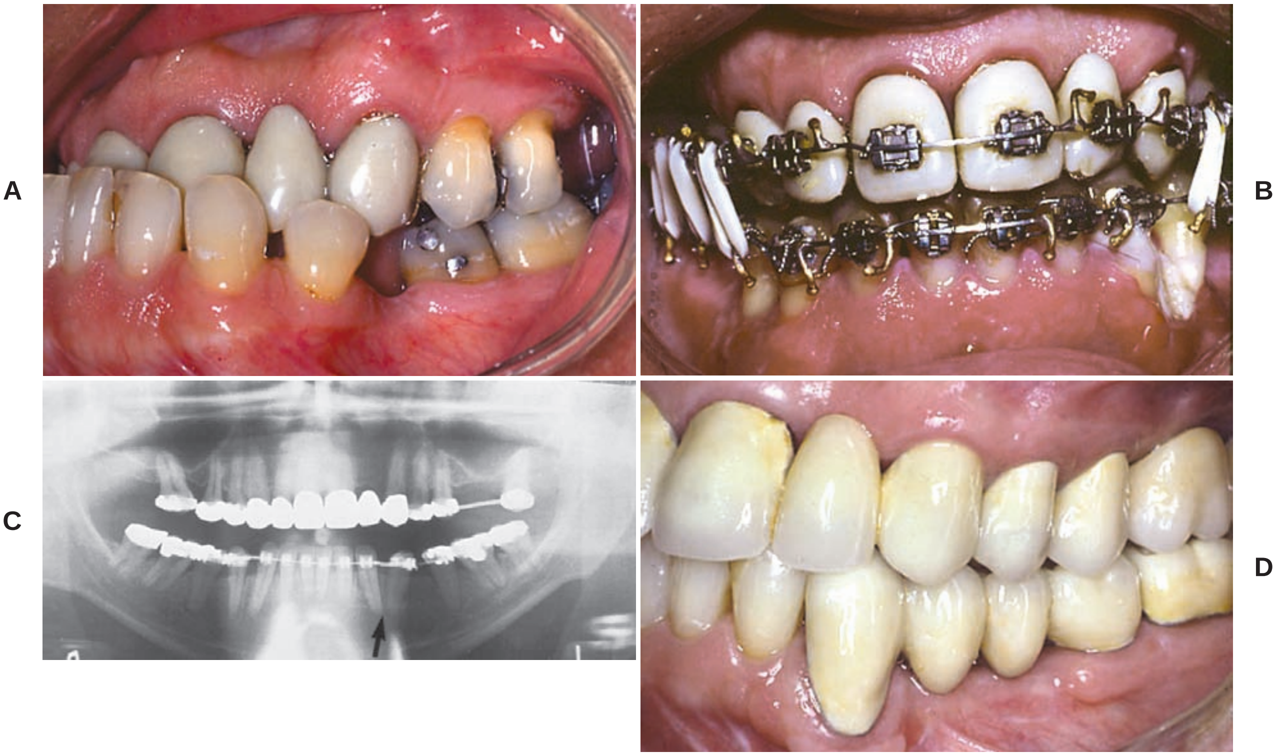


FIGURE 25-42 **A,** Lateral posterior occlusion of a man with a severe Class III condition and supererupted anterior segment. Segmental surgery was planned to intrude the lower incisors before mandibular setback surgery. **B,** The left first premolar tipped distally to make room for the osteotomy. **C,** Panoral film shows inadequate space at the apical area for a safe segmental procedure (*arrow*); nevertheless, surgery proceeded. **D,** Postsurgical infection in the area of No. 21 and No. 22 required the extraction of No. 21 and necessitated bridgework, for which there was no plan.

periodontal breakdown after orthognathic surgery because of ensuing dietary changes, interference with oral hygiene (depending on the mode of fixation), and transitory occlusal trauma.

2. Gingival deficiency with recession

   During the treatment planning stage, orthodontists need to consider the degree of decompensation of the lower incisors as they prepare the patient for jaw surgery. Frequently in Class III patients, for example, lower incisor decompensation requires gingival grafting prior to tooth movement to avoid gingival recession (see Figures 25-24 and 25-26).

3. Pulpal changes

   The osteotomies that are performed, particularly Le Fort I procedures and segmentals, often approximate root apices. Occasionally, after an osteotomy, the affected tooth starts to change color and lose its vitality, and eventually it requires a root canal. The likelihood of loss of vitality is minimal, but it does occur. Careful preparation by the orthodontist and planning by the surgeon should eliminate this annoying complication.

4. Tooth loss

   Tooth loss is an uncommon sequela, but it does warrant brief discussion. Tooth loss occurs, as in Figure 25-42, because of inadequate apical root space (4 mm is the desired amount of separation between apices). Proper preparation of the area to be segmented reduces the probability of tooth loss sequelae. Although this discussion of complications associated with orthognathic surgery is far from complete, it should give the orthodontist an awareness of some of the more common postsurgical sequelae that must be managed in cooperation with the oral surgeon for the overall well-being of the patient. Orthodontists who refer patients for orthognathic surgery should review the informed consent policy of the surgeon's office so that the orthodontist and staff can help their patients understand any aspects that are unclear. The routine surgical practice in the United States is to review potential negative sequelae with the patient before surgery. This is part of the informed consent procedures and is appreciated greatly by patients.[18]

SUMMARY

This chapter began with a discussion of treatment goals and the technologic advances that have helped the orthodontic-surgical team enhance the lives of many patients who were born with facial skeletal disharmonies. The chapter intentionally concluded with a discussion of complications. New surgical technology has broadened the scope of the orthodontist's treatment capability and at the same time has expanded the orthodontist's responsibilities. In his very informative book *Second Opinions*, Jerome Groopman[137] provides a valuable insight from his medical experience to orthodontists and surgeons. He states: "In a predictable world, clinical decision making would be a well-defined, scientific exercise with set methods for diagnosis and treatment. The unfortunate truth is that this is not possible. People adapt differently, physically and emotionally, to each illness (condition) and react in varying ways to a given therapy. This means that diagnosis and treatment cannot be strictly bound by generic recipes, but must be made individual, to be consistent with the particular clinical and psychological characteristics of the person." As the orthodontic specialty and the surgical specialty continue to study factors that reduce risk and enhance success, the surgeon and the orthodontist have the responsibility to integrate many important variables to provide optimal patient care.

Acknowledgments

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CHAPTER 26

The Orthodontist's Role in a Cleft Palate–Craniofacial Team

Katherine W.L. Vig, Ana M. Mercado

OUTLINE

Diagnostic Considerations
- Prenatal Diagnosis of Cleft Lip/Palate
- Detection Rates for Orofacial Clefting
- Ultrasound Technique Limitations
- Three-dimensional Ultrasonography
- Advantages of Prenatal Cleft Diagnosis
- Disadvantages of Prenatal Cleft Diagnosis

The Team Approach

Role of the Orthodontist
- Neonate and Infant (Birth to 2 Years of Age)
- Primary Dentition Stage (2 to 6 Years of Age)
- Mixed Dentition Stage (7 to 12 Years of Age)
- Permanent Dentition Stage

Summary

The American Cleft Palate-Craniofacial Association was established in 1943 to foster a team approach and to serve as an advocate for patients with clefts of the lip and/or palate and their families. The association defined the role of the orthodontist on a cleft palate team and recognized a team approach as the most appropriate method to manage the care of patients with orofacial clefts.

Historically, those children who were born with facial clefting in addition to other manifested craniofacial anomalies underwent a succession of evaluations and hospitalizations by their independent caregivers. This individualized delivery of care, although considered in the best interests of the patients, resulted in additional hospital admissions and multiple instances of general anesthetic administration. In 1972 craniofacial teams became established as an extension of the cleft palate team. This development was in response to clinical geneticists and dysmorphologists becoming increasingly aware that orofacial clefts were part of a phenotypic spectrum of craniofacial anomalies.[1]

The team approach to comprehensive care requires the orthodontist to work collaboratively to determine the appropriate timing and sequencing of treatment in the context of the patient's other health care needs. This interactive, evidence-based, and patient-centered care provides the basis for a rational approach to diagnosis and treatment planning. Just as multiple methods and alternative treatment interventions are available, so also the team approach to management advocates that patients and their parents be aware of the choices through a risk-cost-benefit appraisal. This appraisal allows patients to make informed decisions and to understand the consequences of the different options available, especially in light of emerging technologies and treatment modalities for which long-term outcomes are not available. The document "Parameters for Evaluation and Treatment of Patients with Cleft Lip/Palate or Other Craniofacial Anomalies"[2] was the product of a consensus conference in 1992 to develop guidelines and practices in the care of patients with craniofacial anomalies. The parameters, revised in 2009, also serve as guidelines for the patient-oriented clinical management of those patients with craniofacial anomalies.[3]

The purpose of this chapter is to consider a rational team approach to the orthodontic management of the

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patient with cleft lip and/or palate.[4,5] Orthodontic interventions should be confined to discrete stages in skeletodental development of the craniofacial complex and should not be considered as a continuum of treatment from birth to adulthood.

DIAGNOSTIC CONSIDERATIONS

Clefts of the lip and palate occur in approximately 1 : 700 live births in the United States and are the fourth most common craniofacial birth defect. The incidence varies in different races, and prevalence of cleft type varies by gender. The estimated cost of treatment is about $108,000 for this craniofacial birth defect compared with other birth defects. The high total cost of cleft lip/palate is a reflection of its incidence and also relates to the associated morbidity and mortality.[6]

Cleft lip and/or palate may be diagnosed by prenatal ultrasound, which has become more common because refinements of this diagnostic tool provide images by which congenital and developmental anomalies may be detected more clearly. The ability to make the diagnosis in utero gives the parents the opportunity to be prepared for the birth of their infant with a facial anomaly and to understand the surgical procedures available for repair of the facial cleft. Prenatal counseling provides parents with both a level of awareness and realistic expectations at the time of the delivery. If the diagnosis of a craniofacial anomaly has not been identified prenatally, parents may experience an overwhelming disappointment and sense of guilt when the obstetrician or neonatologist informs them of their baby's birth defect. However, the distinction between a syndromic/nonsyndromic facial cleft and its recurrence risk is the domain of the geneticist, dysmorphologist, or syndromologist, who provides this information to the parents and later to the patient at the appropriate time in his or her maturation.[7]

Prenatal Diagnosis of Cleft Lip/Palate

Ultrasonography is a noninvasive diagnostic tool now widely used as a routine component of prenatal care. Ultrasonography serves to confirm fetal viability, determine gestational age, establish the number of fetuses and their growth, check placental location, and examine fetal anatomy to detect any malformations.[8]

Detection Rates for Orofacial Clefting

Prenatal diagnosis of orofacial clefting is possible with high-resolution ultrasonography. Several studies have shown that ultrasonography can detect 22% to 33% of facial clefting cases.[9-11] In particular, the presence of cleft lip is easier to diagnose sonographically than cleft palate, and detection rates have been reported as high as 38%.[10] Moreover, a recent study showed a 73% detection rate for fetal cleft lip.[12] Prenatal detection of isolated cleft palate is more difficult to achieve, with detection rates as low as 1.4%.[9]

Ultrasound Technique

Christ and Meininger[13] reported that optimal imaging of the fetal face is not reliable with transabdominal ultrasound until gestational week 15. The position of the face and the disproportionate size of the transducer and fetus make it more difficult to show the anatomy of the fetal nose and lips before that point of gestation. Robinson et al.[12] reported that the detection rate for fetal cleft lip is improved greatly when transabdominal sonography is performed at or after 20 weeks of gestation. At that time the lips become more developed and prominent as the fetus grows, allowing for better imaging as long as there is an amniotic fluid interface and no obstructions. Transvaginal sonography, although not routinely used, has been reported to allow earlier visualization of the face and better image resolution, yielding high specificity and sensitivity of prenatal cleft lip detection.[14]

Babcock and McGahan[15] described a systematic approach that allows for fast and thorough sonographic evaluation of the midface structures. Starting with the coronal plane, the soft tissues of the fetal nares and upper lip are examined for continuity (Figure 26-1, *A*). Once a cleft is detected in the coronal view, anatomic assessment continues in the axial plane, evaluating the superficial skin margin of the upper lip, the underlying orbicularis oris muscle, and tooth-bearing alveolar ridge (Figure 26-1, *B*). An isolated cleft lip is diagnosed if discontinuity exists in the upper lip with no evidence of disruption in the underlying alveolar ridge. Cleft lip and palate is diagnosed if a cleft is identified in the lip and disruption of the alveolar ridge, whether unilateral or bilateral, is present. Bilateral clefts of lip and palate are well visualized in the sagittal plane because protrusion of the premaxillary segment is evident.[15,16] Isolated clefts of the hard palate are viewed best in the axial plane[17] (Figure 26-2). Acoustic shadowing from facial bones, which obscure the palatal structures, makes isolated clefts of the hard palate particularly difficult to visualize and diagnose prenatally.[15] Movement of the tongue above the level of the hard palate may suggest the presence of a secondary palate cleft.[18,19] Color Doppler ultrasonography has been used to visualize abnormal flow of amniotic fluid from the mouth to the nasal cavity, a finding that may suggest the presence of a palatal cleft.[20]

Limitations

Various factors may limit the sensitivity of diagnosing an orofacial cleft during ultrasound screening, including an unfavorable position of the fetus, hand or umbilical cord overlying the face, maternal obesity, presence of a multiple gestation, and oligohydramnios (reduced amniotic fluid).[21] Other factors reported include parity (number

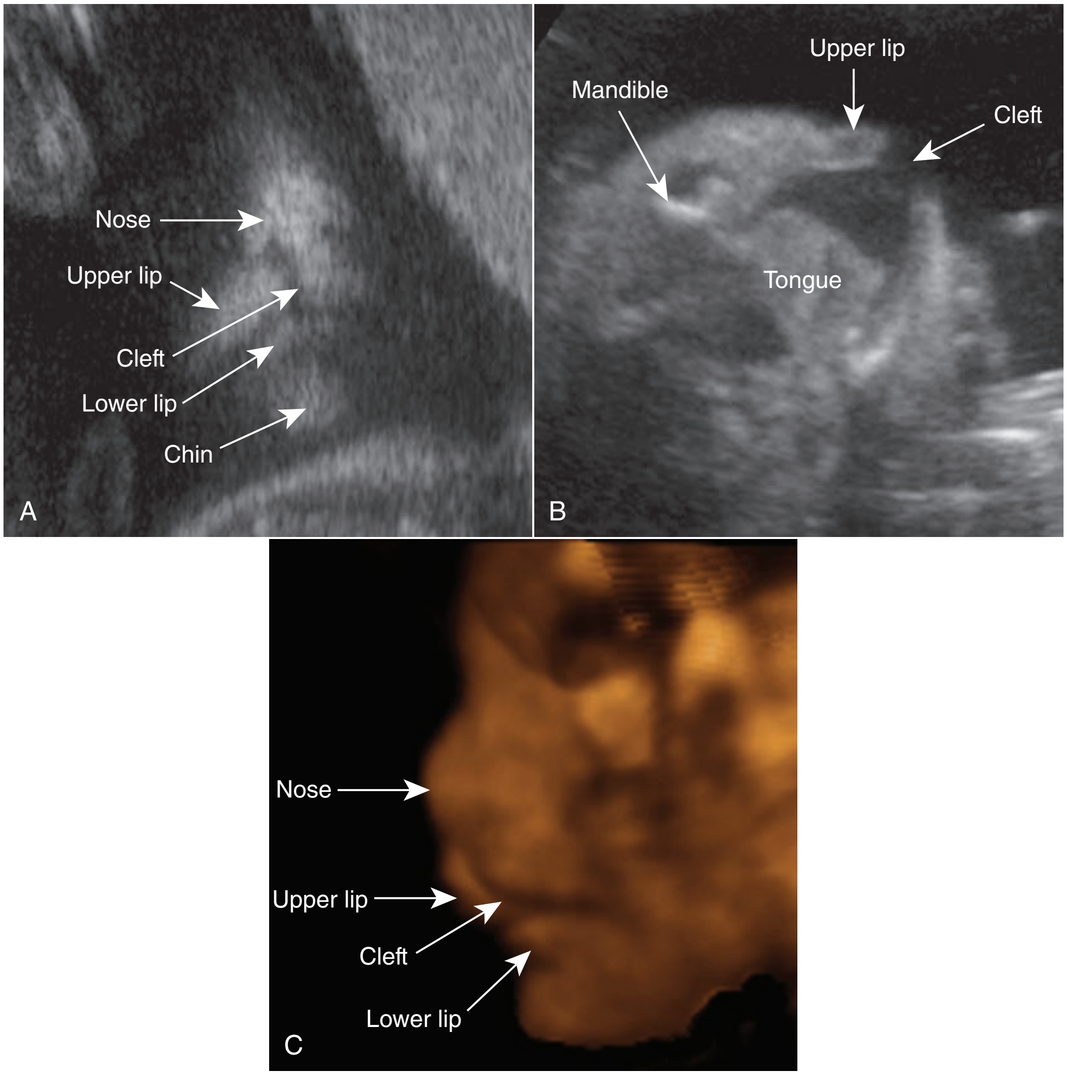

FIGURE 26-1 Transabdominal ultrasonography images of the midface of a fetus with unilateral cleft lip at 21 weeks of gestational age. **A,** Two-dimensional, coronal view: the defect in the upper lip extends into the nostril. **B,** Two-dimensional, axial view at the tongue level: discontinuity in the upper lip skin and muscle is observed. **C,** Three-dimensional frontal oblique view: prominence of the upper lip segments in relation to the nose is evident.

of pregnancies), prior abdominal surgery, and the presence of additional fetal abnormalities.[12]

Three-dimensional Ultrasonography

Three-dimensional ultrasound imaging is a new technology that presents views of the fetal face with greater clarity than the conventional two-dimensional imaging described previously[22] (see Figure 26-1, C). The advantages include viewing of the face in a standard anatomic orientation, manipulation of planar views without concern for fetal movement, identification of the exact location of the planar images relative to the surface facial image, and easy interpretation of the lifelike rendered three-dimensional images by a nontrained observer. The sensitivity of three-dimensional imaging in diagnosing cleft lip and palate is considerably greater than two-dimensional imaging.[23]

Advantages of Prenatal Cleft Diagnosis

There are several potential advantages for informing parents of a prenatal diagnosis of facial clefting[21]:

1. Psychological preparation of parents and caregivers to allow for realistic expectations at the time of delivery
2. Education of parents on the management of the cleft: presurgical neonatal orthopedics, plastic surgery for lip and palate closure, and alveolar bone grafting
3. Preparation for neonatal care and feeding
4. Opportunity to investigate for other structural or chromosomal abnormalities
5. Possibility for fetal surgery

An additional advantage of prenatal diagnosis of cleft lip and palate is the ability of the plastic surgeon to prepare

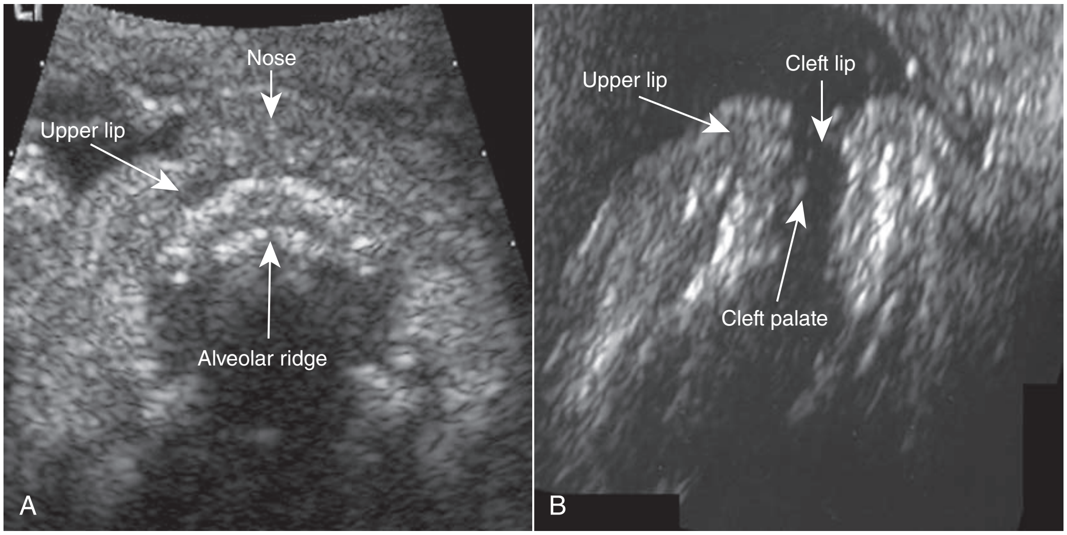

FIGURE 26-2 Two-dimensional axial ultrasonography views of the midface of fetuses in the second trimester of gestation. **A,** Normal anatomy of the palate. The skin of the upper lip and orbicularis oris muscle, the C-shaped alveolar ridge of the maxilla, and the tooth sockets can be evaluated for continuity. **B,** Unilateral cleft lip and cleft palate. Discontinuity of the upper lip, alveolar ridge, and hard palate can be visualized.

a customized plan of management for surgical repair of the cleft once the sonologist characterizes the specific type of cleft and describes the extent of the anomaly. With this information, the plastic surgeon may wish to educate the parents about the severity of the deformity, the need for any adjunctive intervention before surgery, and the predicted outcome of repair.[19]

Disadvantages of Prenatal Cleft Diagnosis

Parents and professionals report an emotional disturbance and high maternal anxiety after prenatal diagnosis of cleft lip/palate is disclosed.[24,25] However, parents of affected children strongly favor being informed and involved in prenatal testing and counseling decisions and view this preparation as valuable despite acknowledging the increased anxiety and dysfunction during pregnancy.[26] As the sensitivity of ultrasound screening in the detection of facial clefts increases, the potential exists for an increased number of families choosing to terminate the pregnancy even in the absence of other malformations.[21] Factors such as perceived burden, expectation of recurrence, religious and cultural beliefs, professional advice, and gestational age at diagnosis are considered influential in the family's decision to terminate pregnancy.[25,27]

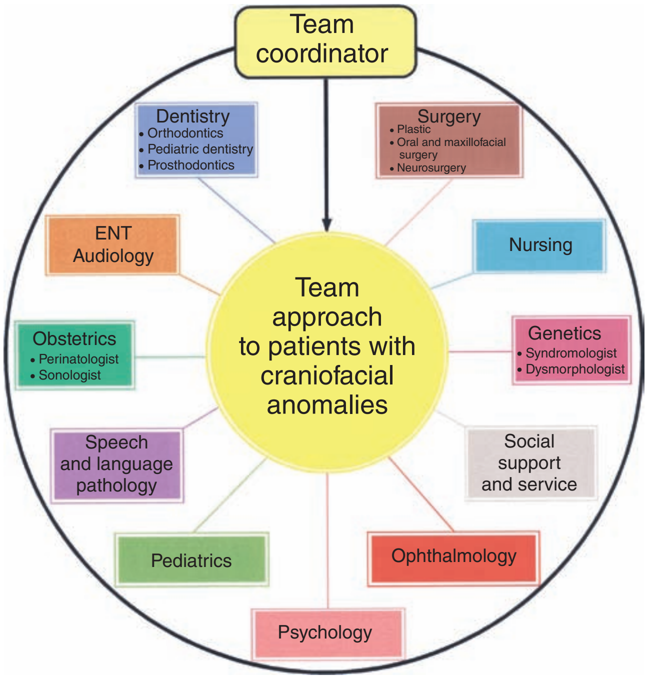

FIGURE 26-3 Members in the team approach to patients with craniofacial anomalies. *(Adapted from Lidral AC, Vig KWL: The role of the orthodontist in the management of patients with cleft lip and/or palate. In Wyszynski D, editor:* Cleft lip and palate: from origin to treatment, *New York, 2002, Oxford University Press.)*

THE TEAM APPROACH

The timing and sequencing of orthodontic treatment are not carried out in isolation from other members of the team but as a result of collaborative decisions made in a coordinated, patient-centered manner sensitive to the patient's and family's needs (Figure 26-3). Several texts provide specific details of treatment intervention, but the overall care of affected infants should rely on interdisciplinary team decisions rather than a series of independent, critical events by individual specialists on a team.[28]

The orthodontist serving on a cleft palate team should consider additional priorities other than malocclusion.

The timing and sequencing of treatment should be sensitive to other interventions by specialists on the team to provide the affected individual with a patient-centered interdisciplinary approach that follows critical pathways.[29,30] These critical pathways have been well defined in a document on critical elements of care for children with special health problems developed by the Washington State Department of Health in 1997.[31] These guidelines were developed through a consensus process including primary and tertiary care providers, family members, and representatives from a health insurance plan.

ROLE OF THE ORTHODONTIST

Timing and sequencing of orthodontic care may be divided into four distinct developmental periods. These periods are defined by age and dental development and should be considered as time frames in which to accomplish specific objectives. Such sequencing avoids the common tendency to allow an early phase of treatment intervention to extend through infancy, childhood, adolescence, and into adulthood. With the understanding that children born with cleft lip and/or palate should be treated by an interdisciplinary team approach, the following four time periods in the child's development provide a framework for discussing and recommending defined objectives.

Neonate and Infant (Birth to 2 Years of Age)

Presurgical orthodontics or neonatal maxillary orthopedics is initiated during the first or second week following birth unless complications arise from other congenital anomalies or medical problems.[32–34] This treatment may be carried out by the orthodontist, the pediatric dentist, or the prosthodontist. The popularity of this early intervention was well accepted in the 1960s and 1970s to eliminate the need for subsequent orthodontic treatment after the segments were aligned. Later reports suggested that although the initial results of lip repair were easier to attain with cosmetic improvement, the procedure seemed to accrue no long-term benefit on the growth of the midface and dentoalveolus. Growth of the nasomaxillary complex and the occlusal results in the primary and mixed dentition appeared clinically similar to those cases without this early treatment intervention. Additionally, the literature also reported that primary bone grafting and associated presurgical maxillary orthopedics further confounded the cause-and-effect relationship.[35] Early or primary bone grafting associated with maxillary orthopedics at the time of primary lip repair may have compromised the long-term follow-up of treated patients. Results suggested that neonatal maxillary orthopedics produced little effect on the developing malocclusions if assessed when the child was 10 years old, especially if treatment had included primary bone grafting to stabilize and prevent maxillary collapse in the infant.[36–38]

Because no long-term benefit was to be gained from these interventions when used indiscriminately on every affected infant, the use of neonatal orthopedics before definitive primary surgical lip repair became an ongoing controversy between clinicians.[36,39] Several institutions continue to advocate early bone grafting and report substantial benefits.[34,40] The perspective of contemporary wisdom is that when provided as an adjunctive procedure to primary definitive lip repair, neonatal maxillary orthopedics does have presurgical benefits. Therefore the popularity of neonatal maxillary orthopedics has returned, albeit with different objectives than to eliminate future need of orthodontic treatment for the child. A considerable literature has developed on this procedure, and the enthusiasm of many clinicians in this field attests to the variety and complexity of the appliances.[30,41–43] The feature that all these appliances, whether fixed or removable, have in common is the ability to adjust the position of the cleft segments into a more ideal relationship before definitive surgical repair of the lip (Figure 26-4).

The benefits from early presurgical orthopedic appliances also need to be weighed against the increased burden of care because of the number of clinic visits necessary to adjust the appliance during the first year of life.[37,41] Neonatal maxillary orthopedics continues to be practiced in a number of centers in the United States and Europe, although contemporary opinion generally does not consider that the evidence supports the intervention as an essential or desirable routine procedure for all infants born with a facial cleft. Nonetheless, the molding of the segments achieved by these appliances does make definitive lip repair easier for the surgeon, especially for patients with a severely protruding premaxilla caused by a bilateral cleft lip.[30]

The results in aligning the cleft segments with appliances have been considered similar to those produced by surgical lip adhesion. Surgical lip adhesion is a partial lip repair procedure often reserved for wide, complete clefts to convert these into incomplete clefts.[44,45] Narrowing a wide cleft and aligning the alveolar segments under the compression forces of the partially repaired lip is advocated. When the alignment of the segments has been achieved following lip adhesion, then definitive lip repair with muscle continuity is performed. This early surgical repair of the lip by an adhesion technique has much to commend it because the parents are not required to remove or adjust appliances, the cosmetic appearance is improved with a minor initial surgical procedure, and postoperative care by the parents is minimal. The most serious problem with this approach is the potential of wound dehiscence and the need for an additional surgery.[35] Typically, lip adhesion is not performed, and contemporary primary surgical lip repair restores continuity of the

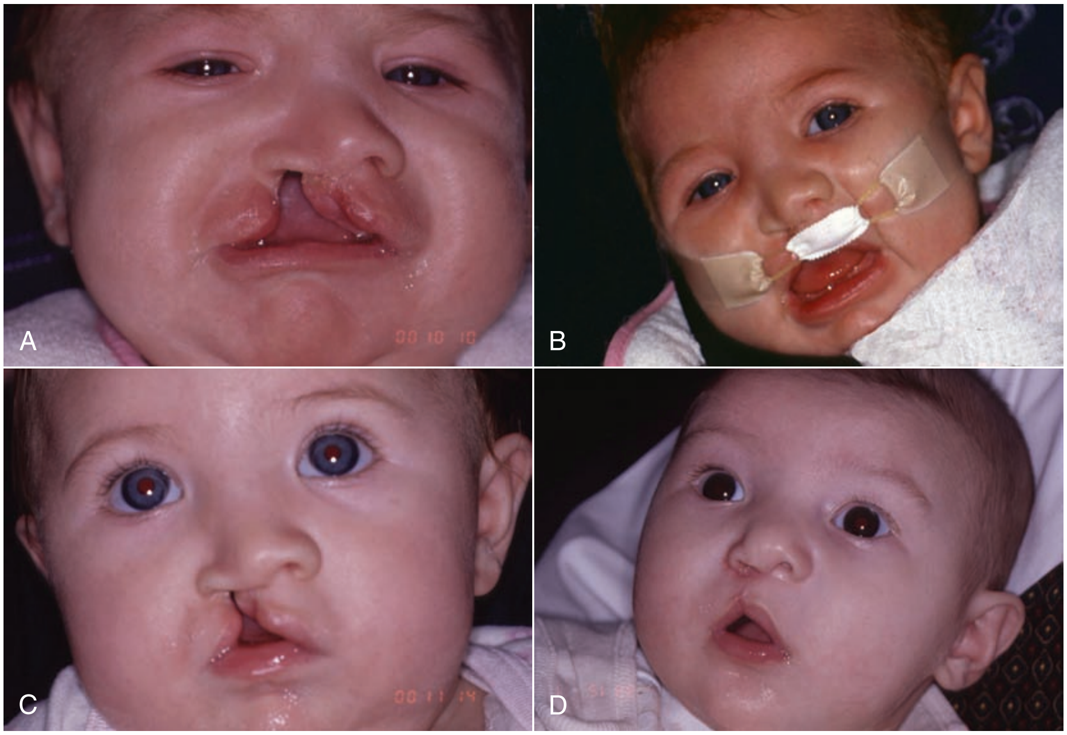

FIGURE 26-4 Neonate with complete unilateral right cleft lip and palate. **A,** Defect before any orthopedic or surgical intervention. **B,** Presurgical orthopedics with lip taping to approximate the segments before cleft lip repair. **C,** Approximated segments immediately before surgery. **D,** Postsurgical view of definitive lip repair.

mucosa, skin, and circumoral musculature in the infant's cleft lip with a single procedure.

Definitive lip repair usually is achieved by the time the infant is 3 to 6 months old, and repair of the palate typically is delayed until 12 months to 2 years of age. Palatal repair is another controversial issue, and many methods are available for repairing just the soft palate or the hard and soft palate simultaneously. The rationale for the timing of the palatal repair is related to the developing speech and language skills of the child, which typically evolve around the first year of age. This rationale is usually in conflict with the effect of early surgical repair and the constraints of scar tissue on the growth and development of the nasomaxillary complex. Early repair of the palate and the resulting scar tissue may have an effect on the growth and development of the maxilla, which is reflected in the occlusion as a crossbite of anterior and posterior teeth. The severity of the malocclusion has been associated with certain surgical methods of palate repair, and evidence from unrepaired clefts in children and adolescents indicates that crossbites in the dentition rarely develop in the absence of surgical repair and resulting scar tissue.

Primary Dentition Stage (2 to 6 Years of Age)

At 2 to 3 years of age the establishment of the primary dentition permits classification of the type of developing malocclusion. This determination may be part of the diagnostic regimen in which the contribution of the skeletal and dental components may be identified.

The facial soft tissues may mask the underlying skeletal deficiency of the midface in young children (Figure 26-5). Growth of the intermaxillary space in three dimensions results in a redistribution of the facial soft tissues as the chubby face of infancy takes on the more mature and defined facial proportions of the child. These facial characteristics start to unmask the underlying skeletal discrepancy more accurately than in the younger child. The dentition often reflects the skeletal relationship, especially if the dentoalveolar component (axial inclination of the teeth) has not compensated for any skeletal discrepancies. Typically, dental compensation for maxillary skeletal deficiency results in retroclination of mandibular incisors with proclination of the maxillary incisors to mask the anteroposterior discrepancy (Figure 26-6).

Because the primary incisors tend to be more upright than their successors, an anterior crossbite may be unilateral or bilateral with or without a functional shift of the mandible. This shift occurs when the child closes the teeth together. To eliminate mandibular shifts, orthodontic treatment may be indicated to remove the interfering contact by tooth movement. This process may involve the maxillary incisors if an anterior crossbite exists or expansion of the posterior segments to eliminate a posterior crossbite (see Figure 26-7, C). If the dental

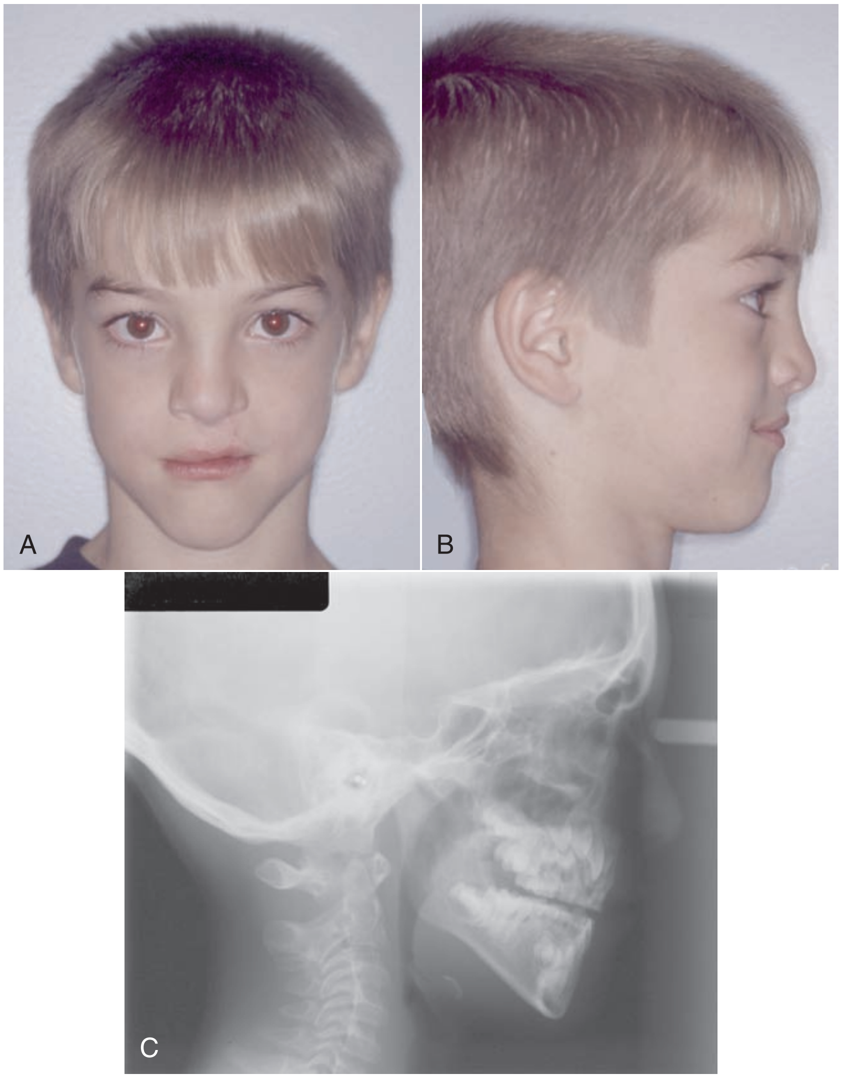

FIGURE 26-5 **A,** Frontal view of a 7-year-old boy with repaired unilateral left cleft lip and palate. **B,** Profile view showing mild bimaxillary retrusion. **C,** Lateral skull radiograph in early mixed dentition.

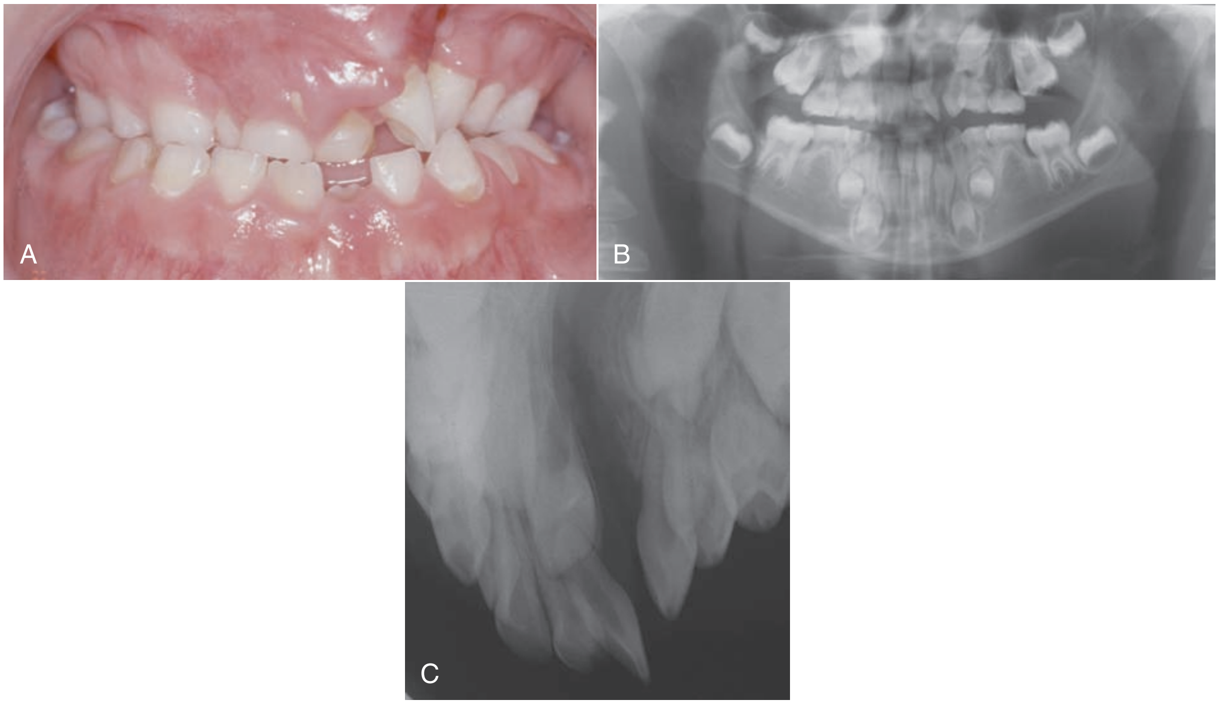

FIGURE 26-6 **A,** Intraoral view in occlusion of the same child as in Figure 26-5. Note the anterior crossbite and the rotated incisor mesial to the cleft. **B,** Panoramic radiograph indicating congenitally absent maxillary lateral incisors, maxillary second premolars, and mandibular second premolars. **C,** Occlusal radiograph showing the bony defect at the cleft site before alveolar bone grafting.

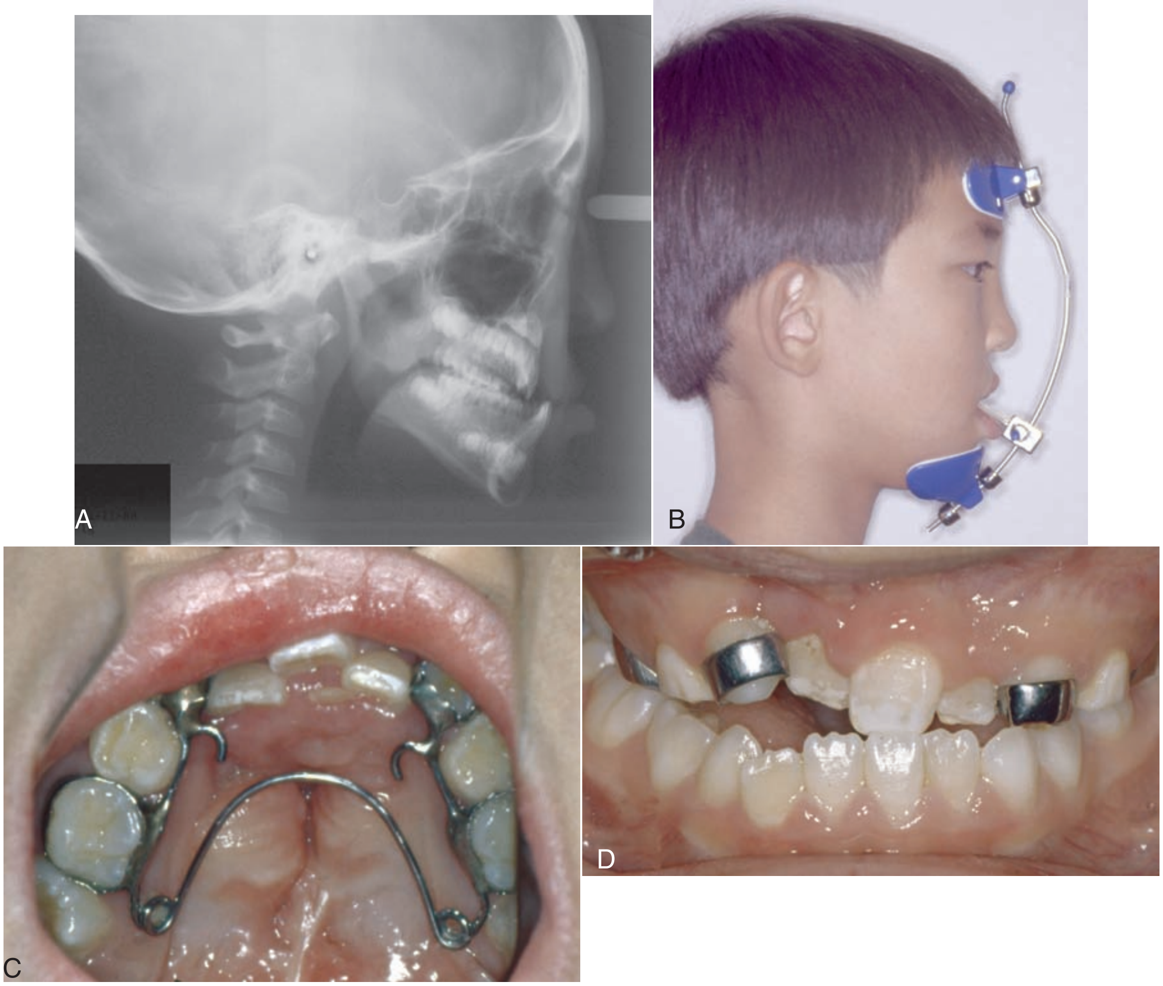

FIGURE 26-7 Eight-year-old boy with repaired unilateral right complete cleft lip and palate with sagittal and transverse maxillary deficiency. **A,** Lateral skull radiograph. Note the 7-mm reverse overjet. **B,** Protraction face mask with elastics attached to palatal hooks on expander. **C,** Palatal expander with bands cemented on the maxillary second primary molars and canines with palatal hooks to attach the protraction face mask. **D,** Lateral and anterior crossbites improving with palatal expansion and maxillary and dental protraction. *(Adapted from Lidral AC, Vig KWL: The role of the orthodontist in the management of patients with cleft lip and/or palate. In Wyszynski D, editor:* Cleft lip and palate: from origin to treatment, *New York, 2002, Oxford University Press.)*

crossbite relationship is a continuing problem once the dentition is established, it may be a reflection of the underlying skeletal discrepancy for which growth modification and redirection may be indicated with a protraction face mask (Figure 26-7). In cases of bilateral cleft lip and palate, severe constriction of maxillary posterior segments often is associated with bilateral crossbite and protrusion/extrusion of the premaxillary segment (Figure 26-8).

The orthodontist should consider many factors in determining when to initiate orthodontic treatment during the primary dentition stage. These factors include the ability of the child to cooperate, the severity of the malocclusion, timing of secondary bone grafts, and the need for future orthodontic treatment in the early mixed or permanent dentitions. Contemporary opinion recognizes a need for orthodontic treatment in the early mixed and permanent dentitions. However, no strong evidence supports a benefit from routinely treating dental malocclusions in the primary dentition, suggesting that orthodontic treatment may be best delayed until it can be combined with other treatment goals and thus shorten the overall duration of treatment.

Severe skeletal discrepancies in the primary dentition are a more complex problem. Modification or redirection of growth has been advocated, and the use of functional or orthopedic appliances, including the forward protraction face mask, has been reported to have some success.[46,47] More commonly, the "apparent correction" is achieved by a transient change in the position of the teeth only, so that with subsequent growth the skeletal discrepancy once again is reflected in the reestablishment of the malocclusion. Early treatment procedures, in common with neonatal maxillary orthopedics, require a

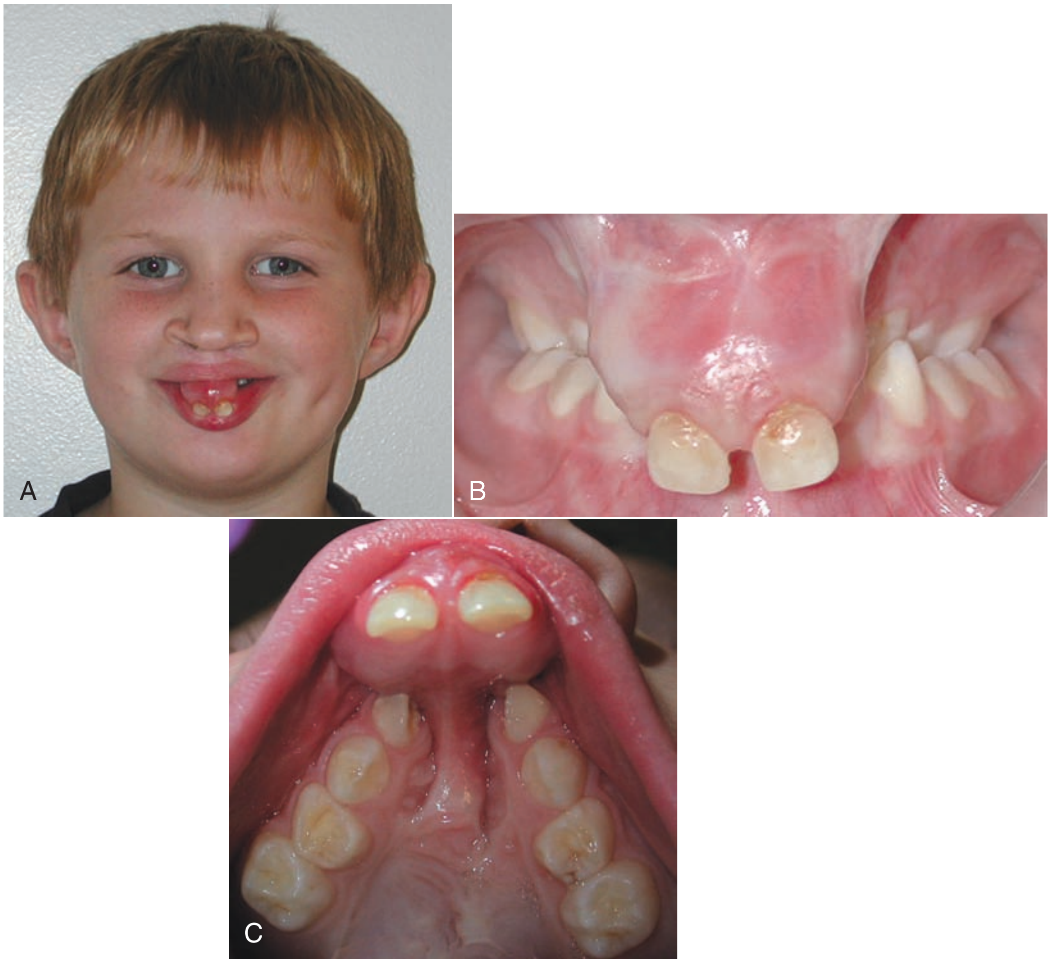

FIGURE 26-8 **A,** Five-year-old boy with repaired bilateral complete cleft lip and palate. Note the severe extrusion of premaxillary segment. **B,** Frontal intraoral view showing premaxillary segment out of the plane of occlusion. **C,** Maxillary occlusal view showing severe constriction of posterior segments and extrusion of premaxillary segment.

long-term follow-up period to evaluate the outcome of treatment when the child reaches adolescence (Figure 26-9). Excessive changes attributable to therapeutic growth modification now are considered to be the exception rather than a predictable outcome of this early intervention.[48,49] One must carefully consider the severity of the skeletal discrepancy to determine the likelihood of successful growth modification and subsequent long-term results compared with conventional orthognathic surgery at a later stage. A more conservative option may be to provide a combined orthodontic/orthognathic surgery treatment plan than to promote long-term growth modification strategies that ultimately may not be successful.

Mixed Dentition Stage (7 to 12 Years of Age)

The transition to the mixed dentition starts at 6 to 7 years of age with the eruption of the first permanent molars and incisors. Further growth of the craniofacial complex often accentuates a previously mild skeletal discrepancy (Figure 26-10). As the permanent incisors erupt adjacent to the cleft site, they typically are rotated, misplaced, malformed, or hypoplastic. In addition, incisors may be supernumerary, absent, or peg shaped. These characteristics are considered the result of early disruption of the dental lamina at the cleft site reflected in the developing tooth germs (Figures 26-11 and 26-12). Constriction of the maxilla with a characteristic V-shaped arch form contributes to the posterior crossbite relationships usually seen in the mixed dentition. Maxillary expansion appliances now can be anchored on the permanent first molars and extended anteriorly to improve arch form while correcting the crossbite (Figure 26-13).

Because deficiency of tissue is an inevitable consequence of facial clefting, not only are the teeth missing but also the supporting alveolar bone at the cleft site is compromised. In the past, rehabilitation of the maxillary dentition depended on the expertise of the prosthodontist to replace the missing teeth and alveolus in the cleft defect with an overdenture. The challenge to restore the

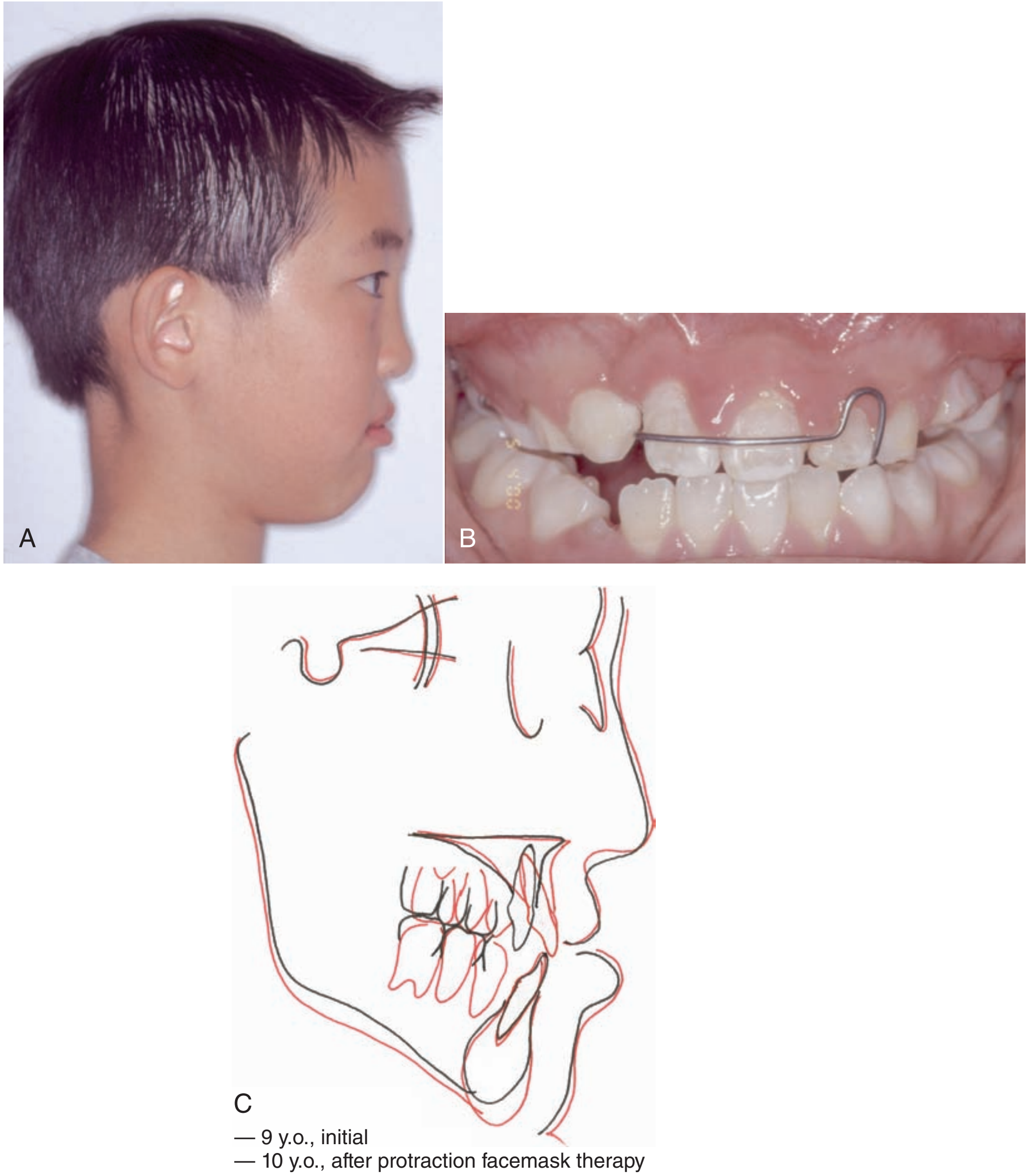

FIGURE 26-9 **A,** Facial profile after 9 months of protraction face mask therapy and palatal expansion (same patient as in Figure 26-7). **B,** Intraoral view with correction of anterior and posterior crossbites; maxillary retainer is in place. **C,** Superimposition of initial and post-protraction lateral cephalogram tracings showing correction of reverse overjet and mild maxillary advancement.

missing tissue at the cleft site was resolved with the advent of secondary alveolar bone grafting in the 1970s.[50–52] This bone grafting procedure provided the orthodontist with one of the most important milestones in managing the cleft site: restoration of an uninterrupted, continuous alveolar ridge that allows for eruption of teeth into the graft and orthodontic movement of teeth into the cleft site (Figure 26-14). Additionally, placement of osseointegrated implants is now possible with prosthetic replacement of missing teeth. The elimination of the residual cleft provided a major advance in the contemporary management of the cleft maxilla and is an example of the outcome of a coordinated and problem-oriented approach to developing new strategies in treatment protocols.[50,53,54]

Primary Alveolar Bone Grafting. Most cleft palate teams in the United States have discontinued primary alveolar bone grafting in the neonate following a 5-year posttreatment outcome study in 1972 by Jolleys and Robertson.[36] However, the case for early bone grafting has been defended and, although controversial, continues to be practiced by several institutions and craniofacial teams.[34]

Secondary Alveolar Bone Grafting. By definition secondary or delayed alveolar bone grafting is performed after primary lip repair.[51,52] The age at which the bone

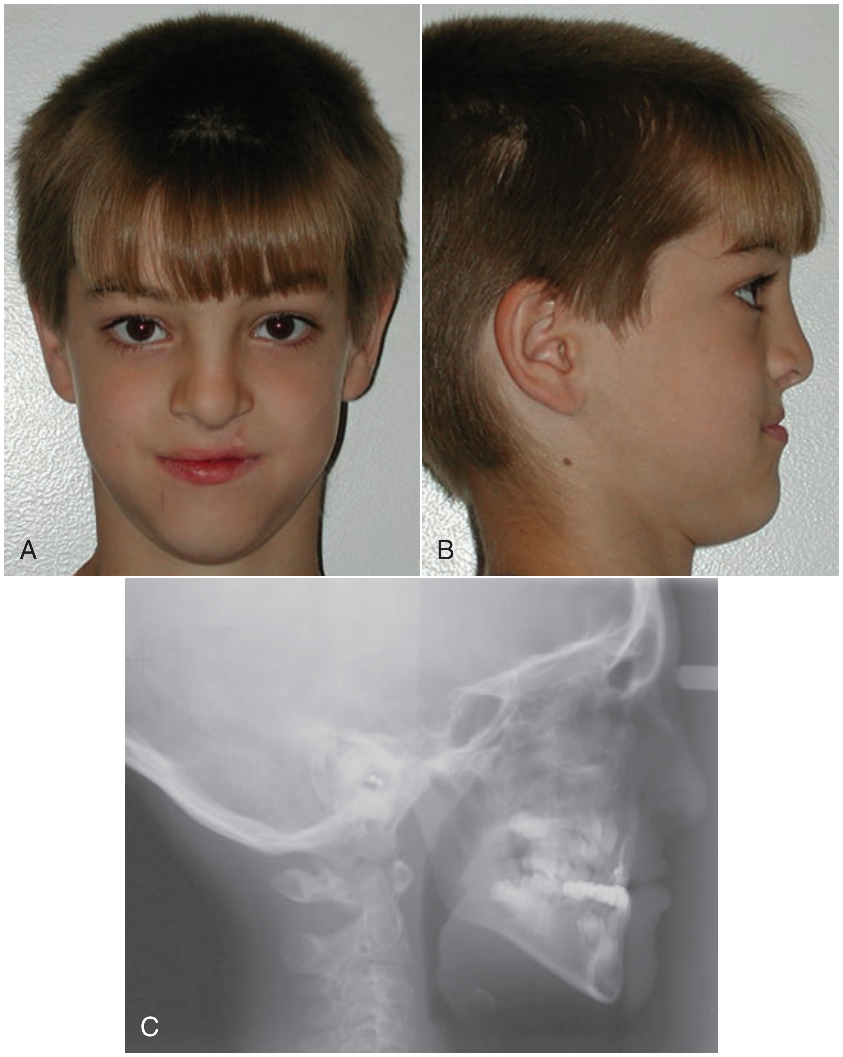

FIGURE 26-10 **A,** Same patient as in Figures 26-5 and 26-6 shown at 9 years of age. **B,** Profile view showing mild midfacial deficiency. **C,** Lateral skull radiograph in mixed dentition with anterior crossbite.

graft is placed defines whether it is early secondary bone grafting (2 to 5 years), intermediate or secondary bone grafting (6 to 15 years), or late secondary bone grafting (adolescence to adulthood).

Intermediate or Secondary Alveolar Bone Grafting (6 to 15 years of age). The success of this intervention requires collaborative treatment planning among the orthodontist, surgeon, and other team members.[55–58] Secondary alveolar bone grafting offers five main benefits:

1. Provision of bone support for unerupted teeth and those teeth adjacent to the cleft. If a bone graft is placed before eruption of teeth adjacent to the cleft, it will improve the periodontal support of those teeth. If a bone graft is placed after eruption of the canine, the bone will not improve the crestal height of support and will resorb quickly to its original level.
2. Closure of oronasal fistulae. By using a three-layered closure technique, with the graft sandwiched between the two soft tissue planes, an increased success rate of fistula closure has been reported.
3. Support and elevation of the alar base on the cleft side. This benefit helps to achieve nasal and lip symmetry and provides a stable platform on which the nasal structures are supported. If this procedure is performed alone or is combined with alar cartilage revisions, improved aesthetic changes occur.
4. Construction of a continuous arch form and alveolar ridge. This benefits the orthodontist for moving teeth bodily and for uprighting roots into the cleft site. A continuous arch form also benefits the surgeon and prosthodontist by enabling a more aesthetic and hygienic prosthesis in preparation for implants to be placed when teeth are missing.
5. Achieve stabilization and some repositioning of the premaxilla in those patients with a bilateral cleft. Controversies concerning alveolar bone grafting require a rational and evidence-based approach for resolution. These controversies relate to the timing of

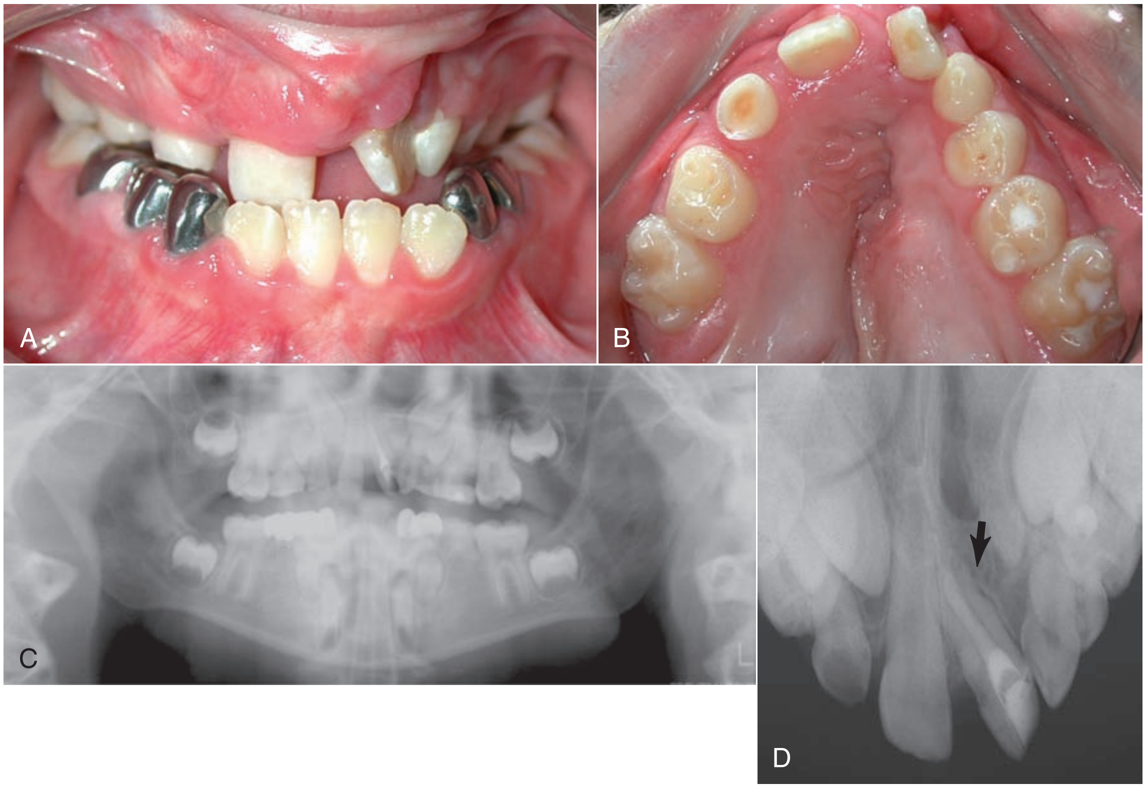

FIGURE 26-11 **A,** Same patient as in Figure 26-10. Intraoral view showing bilateral posterior and anterior crossbites. Note severely rotated maxillary central next to the cleft. **B,** Maxillary occlusal view showing V-shaped arch form with palatal scarring. **C,** Panoramic radiograph showing excessive angulation of maxillary central next to the cleft. Maxillary right first primary molar was lost prematurely. All first permanent molars are erupted. **D,** Occlusal radiograph showing successful alveolar bone grafting (the *arrow* points to cancellous bone at the cleft site). Note decayed and endodontally treated maxillary left central incisor. A developing maxillary left lateral incisor is now evident at the grafted cleft site.

the alveolar bone graft, the sequencing of orthodontic treatment to correct a transverse discrepancy with palatal expansion, and the sites and types of bone for the graft.[59–61]

Timing. The timing of surgery depends more on dental development than on chronologic age. Ideally, the permanent canine root should be half to two thirds formed at the time the graft is placed (see Figure 26-14). Permanent canine root formation generally occurs between the ages of 8 and 11 years. Rarely is the graft placed before this time, although occasionally the graft may be placed at an earlier age to improve the prognosis of a lateral incisor. Once teeth have erupted into the cleft site, their periodontal support will not improve with a bone graft. Instead, the height of the crest of alveolar bone resorbs to its original level. For this reason, performing the graft before the eruption of the permanent canine is recommended. If the lateral incisor is on the distal side of the cleft, the graft should be placed earlier. Results from primary bone grafting indicate an adverse effect on maxillary development but, because maxillary growth is almost completed by 10 years of age, performing secondary alveolar bone grafting at this age should have minimal, if any, effect on subsequent facial growth and development.

Sequencing. Secondary bone grafting has been divided into early (2 to 5 years of age), intermediate (6 to 15 years of age), and late (16 years to adult). Since Bergland et al.[55] published the results from the Oslo study in which 378 consecutive patients had undergone alveolar bone grafting, contemporary opinion supports the intermediate period as the most appropriate time for grafting. Bone grafting in the intermediate period has the greatest benefits and least risk for interfering with midfacial and skeletodental growth and development. The sequencing of procedures surrounding alveolar bone grafting requires interdisciplinary communication and cooperation resulting in better and more predictable patient care. The general or pediatric dentist ensures that any decayed teeth, especially those adjacent to the cleft, are restored before the grafting procedure. Patient and parents are instructed on good oral hygiene practices to maintain at home. In addition, orthodontic treatment may be required presurgically to reposition maxillary teeth that are in traumatic occlusion or to expand a severely constricted maxilla, thus providing the surgeon better accessibility to the cleft defect. Any erupted teeth

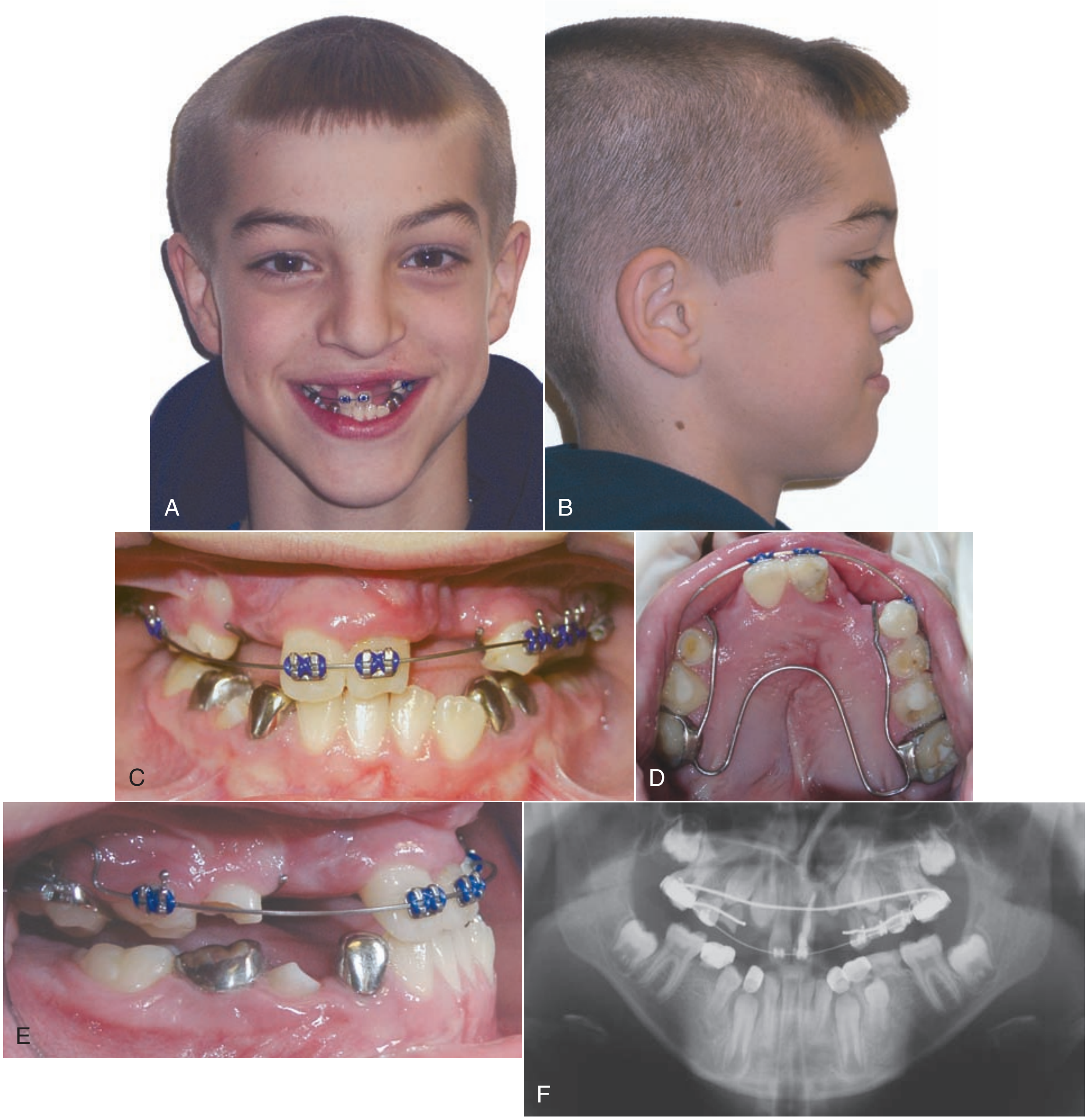

FIGURE 26-12 **A,** Same patient as in Figures 26-5, 26-6, 26-10, and 26-11 shown at 11 years of age undergoing phase I orthodontic treatment (maxillary arch only). **B,** Profile view showing more marked midfacial deficiency. **C,** Intraoral view showing limited bonding of orthodontic appliances in maxillary arch, correction of anterior and posterior crossbites, and alignment of incisors. **D,** Maxillary occlusal view shows palatal expander in place and improved arch form. **E,** Right buccal view showing proclined maxillary incisors, retroclined mandibular incisors, and Class III molar relationship. **F,** Panoramic radiograph showing alignment and uprighting of the endodontically treated maxillary left central incisor adjacent to the cleft site (compare with Figure 26-11, *C, D*).

adjacent to the cleft that have poor periodontal or endodontic prognosis should be extracted at least 2 months in advance to allow healing of mucosal tissues before surgery.

Surgical Technique. The grafting procedure uses tissue lining the cleft defect to construct a nasal floor and close the nasal side of the oral-nasal fistula. The cleft lining is elevated in a subperiosteal plane that leaves bare the osseous margins of the cleft. Cancellous bone taken from the ilium, cranium, or mandibular symphysis is then packed into the cleft defect. Cancellous bone is preferred over cortical bone because it revascularizes more rapidly and is less likely to become infected.[61] Once the cleft defect is packed with bone and the margins are overpacked, soft tissue coverage of the graft is required. The surgeon determines the choice of the donor site from which the bone is harvested. Traditionally, the iliac crest, ribs, and tibia have been used because of their abundant

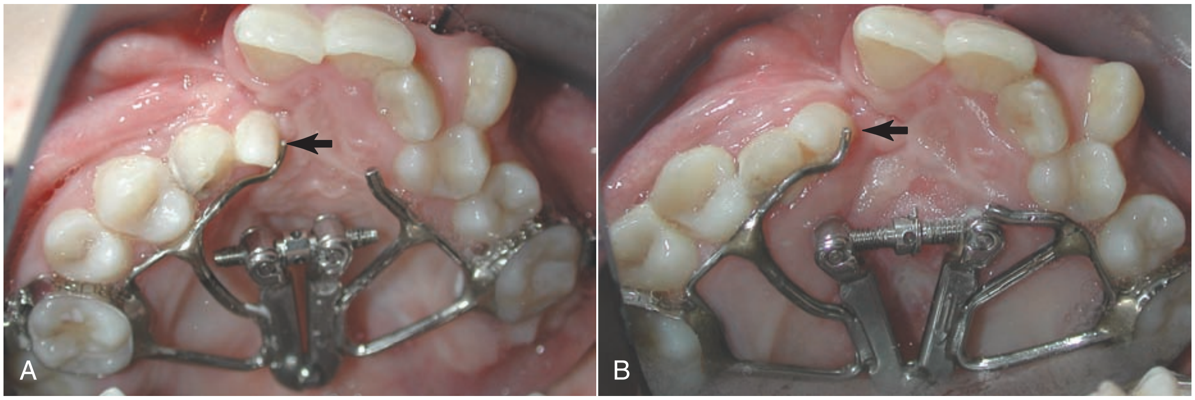

FIGURE 26-13 **A,** Maxillary occlusal view of 12-year-old patient with repaired unilateral right cleft alveolus. Palatal Spider appliance (Leone S.P.A. Orthodontic Products, Oxnard, California) cemented in place. Adjustments of the screw system produce differential expansion in the premolar and canine regions while pivoting around a posterior hinge next to the molars. *Arrow* points to right lateral incisor. **B,** Maxillary arch after 8 months of expansion. Note improved position of right segment (*arrow* points to lateral incisor) in relation to maxillary central incisor, with minimal expansion at the molar region.

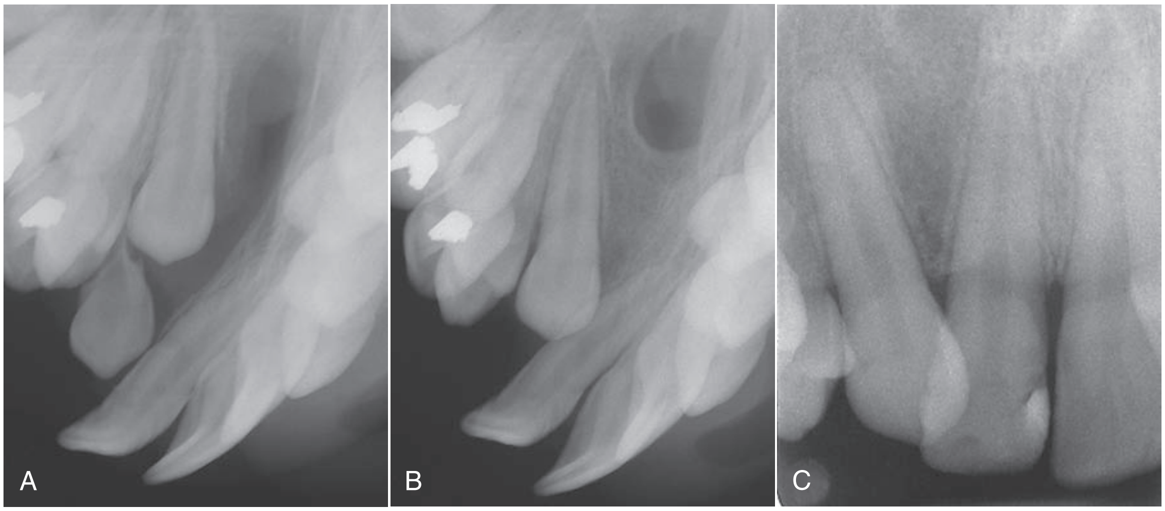

FIGURE 26-14 **A,** Occlusal radiograph of bone defect at the cleft site before alveolar bone grafting. Lateral incisor is missing and canine has more than two thirds of its root developed (close to eruption). **B,** Occlusal radiograph taken 7 months after alveolar bone grafting. Note excellent fill of cleft defect with cancellous bone. Canine is erupting through the grafted bone. **C,** Periapical radiograph taken 4 years after alveolar bone grafting. Note excellent alveolar crest levels adjacent to central incisors and canine.

supply of cancellous bone. The morbidity of harvesting bone from these sites results in most patients being hospitalized postsurgically because of complications associated with the donor site more so than with the oronasal recipient site. The cranium has become an alternative site from which to harvest cancellous bone because of the lack of associated discomfort and the amount of hospitalization time involved. However, the operating risks are higher and the abundance of cancellous bone is less than from the iliac crest. The mandibular symphysis is another donor site but should be recommended only when the permanent mandibular canines have been located so as to minimize the chances of injuring these developing teeth.

Orthodontic Considerations Associated with Secondary Bone Grafting. Orthodontic concerns regarding secondary bone grafting relate to the transverse dimension, incisor alignment, and eruption of the maxillary canines.

The Transverse Dimension. Orthodontic expansion of the posterior segments (see Figure 26-7, C) preoperatively may improve the occlusion but also widen an existing fistula. The expansion provides better access at surgery for incision and elevation of flaps with closure of the palatal and vestibular oronasal fistulae following the cancellous alveolar bone graft. Expansion also improves the buccolingual orientation of the collapsed posterior segment with the anterior segment, restoring arch symmetry (Figure 26-15). Retention of the corrected crossbite with orthodontic appliances postsurgically may be indicated because the bone graft is unlikely to stabilize the expansion.

Incisor Alignment. Alignment of incisors adjacent to the cleft, which typically are rotated, displaced, or tipped, is limited by the available bone into which the roots of the teeth may be moved. If appliances have been placed presurgically, individual orthodontic tooth movements should be delayed until 2 to 6 months following placement of the bone graft. The early movement of the roots into the grafted bone appears clinically to consolidate the alveolar bone and improve the crestal alveolar height. The orthodontist should confirm with the surgeon on the timing of tooth movement into the grafted cleft site. In bilateral cleft lip and palate cases, a vertically extruded premaxilla can be repositioned upward with the use of a labial intrusion archwire, moving the incisors en masse with the bone in vertical alignment with the posterior segments prior to bone grafting (see Figure 26-15).

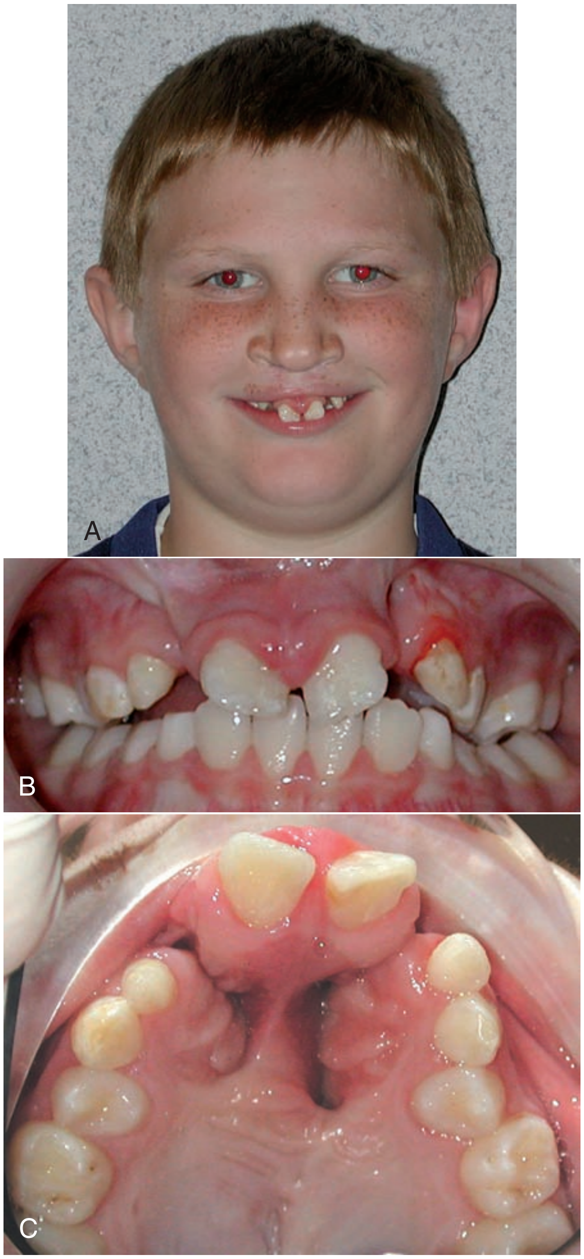

FIGURE 26-15 **A,** Same patient as in Figure 26-8 shown at 11 years of age after maxillary expansion, orthodontic repositioning of premaxilla, and alveolar bone grafting. **B,** Frontal intraoral view showing premaxillary segment in better vertical alignment with the rest of the arch. **C,** Maxillary occlusal view showing improved arch form. There are persistent palatal fistulas, which are adequately obturated by a Hawley retainer (not shown).

Eruption of the Maxillary Canine. Following surgery, the maxillary canine erupts through the grafted bone (see Figure 26-14). With orthodontic movement of teeth, sufficient space is created in the arch to allow the canines to erupt successfully. Removal of unerupted supernumerary teeth usually is performed at the time that the bone graft is placed to create an unobstructed path of eruption for the canine. Often the canine will erupt rapidly following the bone graft. If the lateral incisors are malformed or absent, especially in patients with bilateral clefts, the canine is encouraged to erupt adjacent to the central incisors. Closing the edentulous space is an advantage, thus avoiding the need for a prosthetic replacement of the absent lateral incisors. However, "canine substitution" needs to be considered in the context of the occlusion, crown morphology, and the need for orthognathic surgery.

Permanent Dentition Stage

With the eruption of the canines and premolars, the permanent dentition is established. During this time, the adolescent growth spurt and onset of puberty occur. The skeletal discrepancy becomes accentuated, and facial appearance and occlusal relationships deteriorate (Figures 26-16 and 26-17). These changes occur at a time when individuals are most self-conscious about their body image and facial appearance. Facial scars already detract from the cosmetic appearance, and derogatory comments by peers may have a profound psychological effect. At this time, involution of the adenoidal lymphoid tissue occurs, often with impairment of speech from the resulting hypernasality. With a decline in cosmetic appearance and speech communication, many patients have a special need for early intervention by the surgeons, orthodontists, speech therapists, and psychologists.

Growth Considerations. Patients with unilateral complete clefts of the lip and palate typically become more maxillary deficient and mandibular prognathic in their appearance, because of sagittal maxillary deficiency. Vertical maxillary deficiency may result in overclosure of the mandible to achieve occlusion of the teeth, thus accentuating the Class III tendency. Clinical evaluation of the extent of overclosure contributing to the Class III relationship by measuring the interocclusal clearance at the

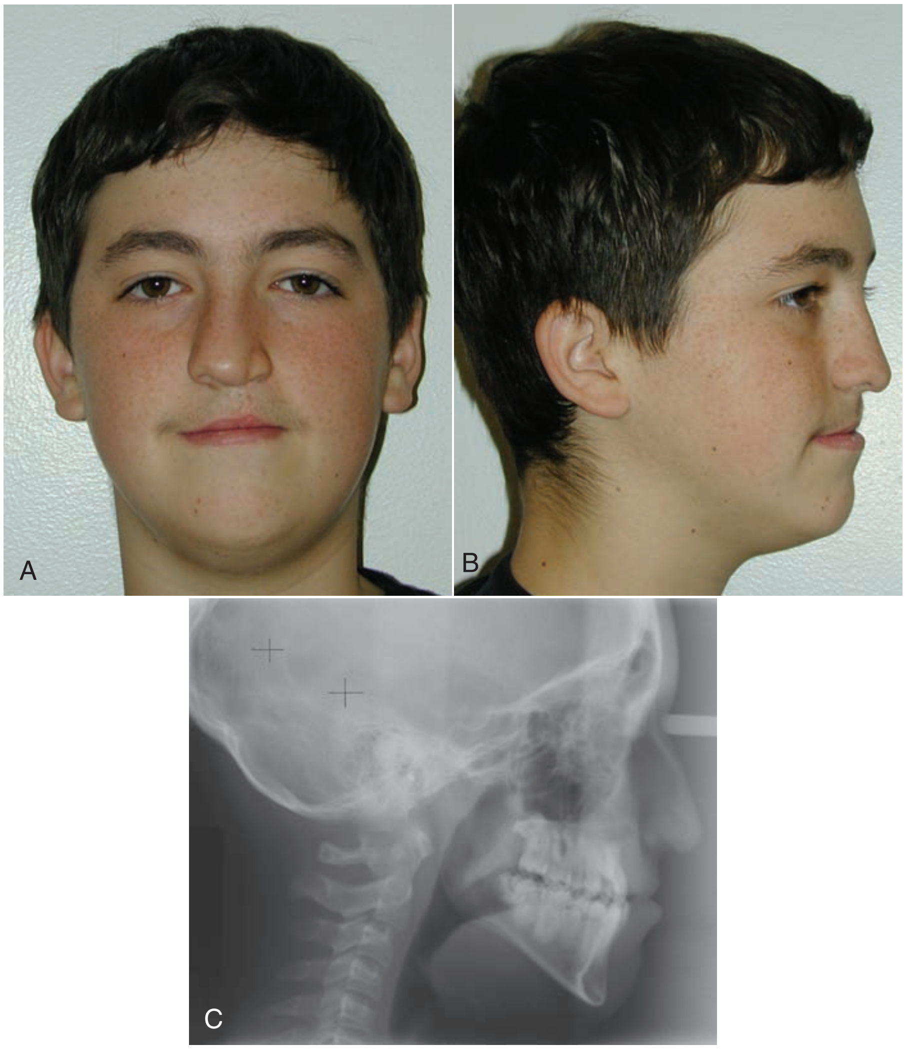

FIGURE 26-16 **A,** Frontal view of 14-year-old boy with repaired unilateral left complete cleft lip and palate. **B,** Profile view reveals a concave profile with midfacial deficiency. **C,** Lateral skull radiograph shows a Class III skeletal pattern, proclined maxillary incisors, and retroclined mandibular incisors.

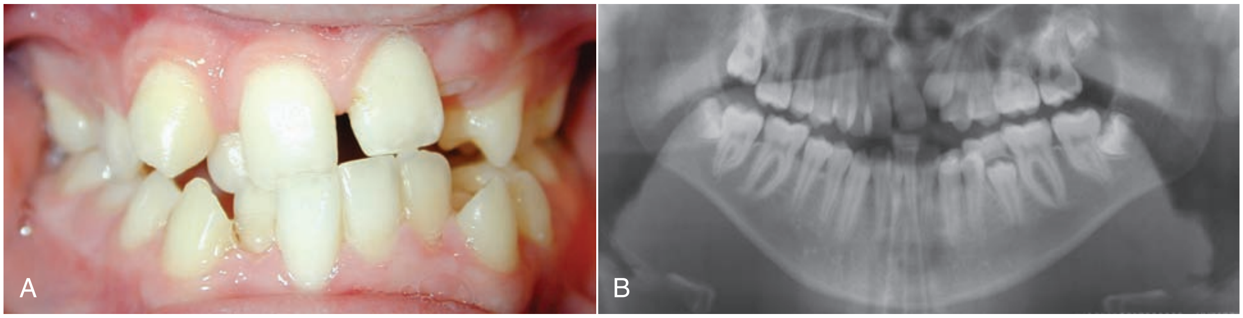

FIGURE 26-17 **A,** Intraoral view of same patient as in Figure 26-16. Maxillary deficiency and dental crowding in both arches contribute to the anterior crossbite relationship with slight (1- to 2-mm) anterior mandibular shift. Note constricted maxillary premolar segments. **B,** Panoramic radiograph reveals near completed permanent dentition with missing maxillary left lateral incisor.

premolar region with the patient in resting posture is important. The Class III dental relationship in the sagittal plane may accentuate discrepancies in the transverse plane and are often manifested as posterior crossbites. To evaluate the occlusion, study models are necessary to assess the relationship of the maxillary to mandibular dentition in all three dimensions.

The pattern of facial growth results from the interaction of genetic and environmental factors. Continued growth in early adulthood may enhance or detract from

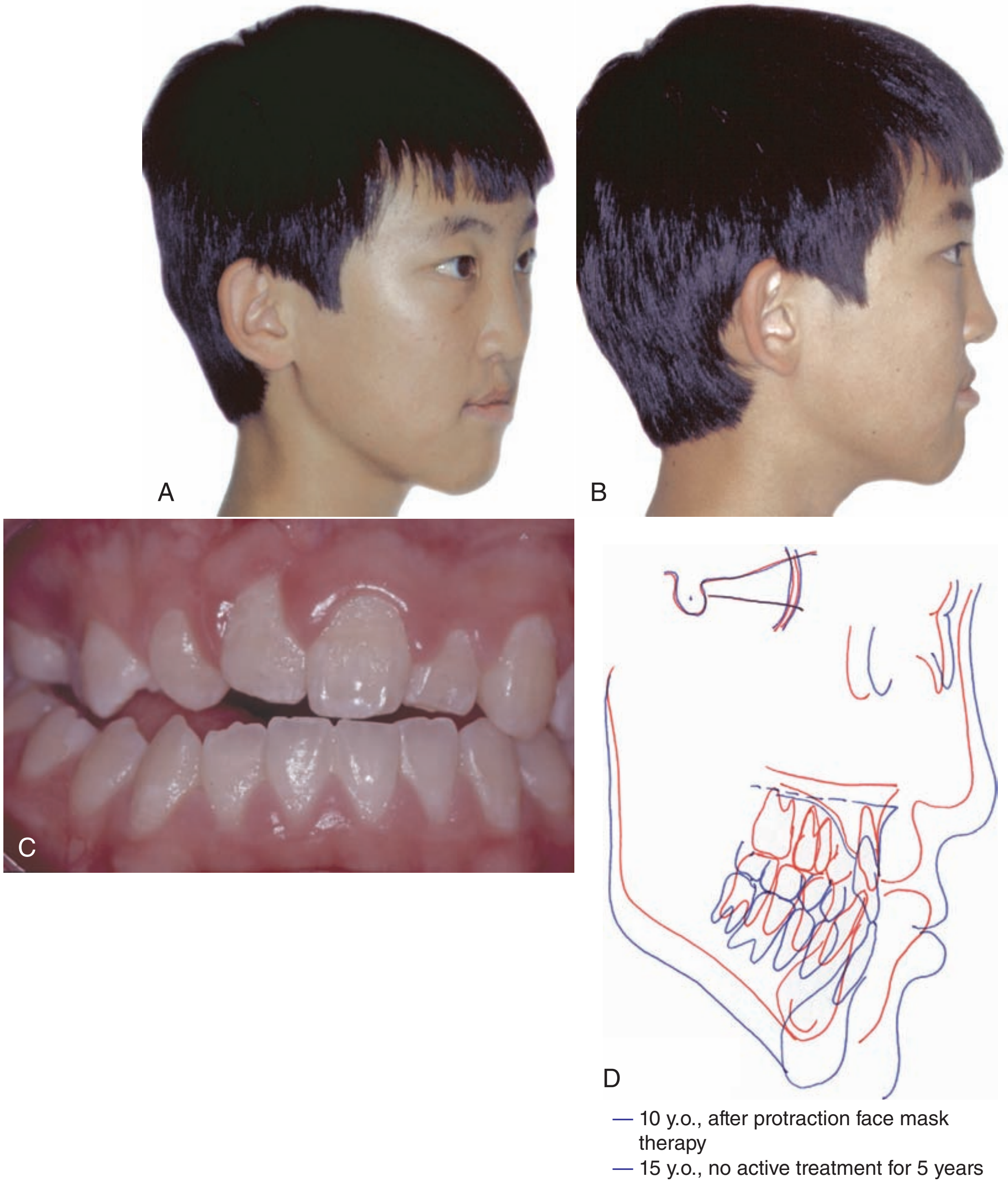
A
B
C
D
— 10 y.o., after protraction face mask therapy
— 15 y.o., no active treatment for 5 years

FIGURE 26-18 **A,** Same patient as in Figures 26-7 and 26-9 shown at 15 years of age. No active orthodontic treatment had been delivered for 5 years after completion of protraction face mask therapy. **B,** Profile view shows a straight to slightly concave profile with long lower facial height. **C,** Intraoral view shows anterior edge-to-edge relationship, mild incisor rotations, and constricted maxillary posterior segments. **D,** Superimposition of lateral cephalogram tracings from immediately after protraction and 5 years after protraction (no active treatment) showing skeletal growth in a predominantly vertical downward pattern.

treatment results that have been obtained during childhood and adolescence (Figure 26-18). These dynamic properties of the face make the management of facial growth challenging and rewarding.[46,47] A patient whose treatment in the permanent dentition allowed camouflage of the skeletal discrepancy and prosthetic replacement of the congenitally missing maxillary right lateral incisor is illustrated in Figures 26-19 to 26-21.

Skeletal-Facial Considerations. Examination of facial balance and proportions is critical in determining a treatment plan that combines surgery and orthodontics. This clinical evaluation should be carried out with the patient standing so that one can consider the overall stature. Full-face and profile assessment provides a database incorporating all three dimensions, and this information should be documented with the patient in resting position and also in occlusion. Cephalometric analysis and prediction tracings provide further information for deciding whether a patient can be treated by orthodontics alone or by orthodontics and an orthognathic

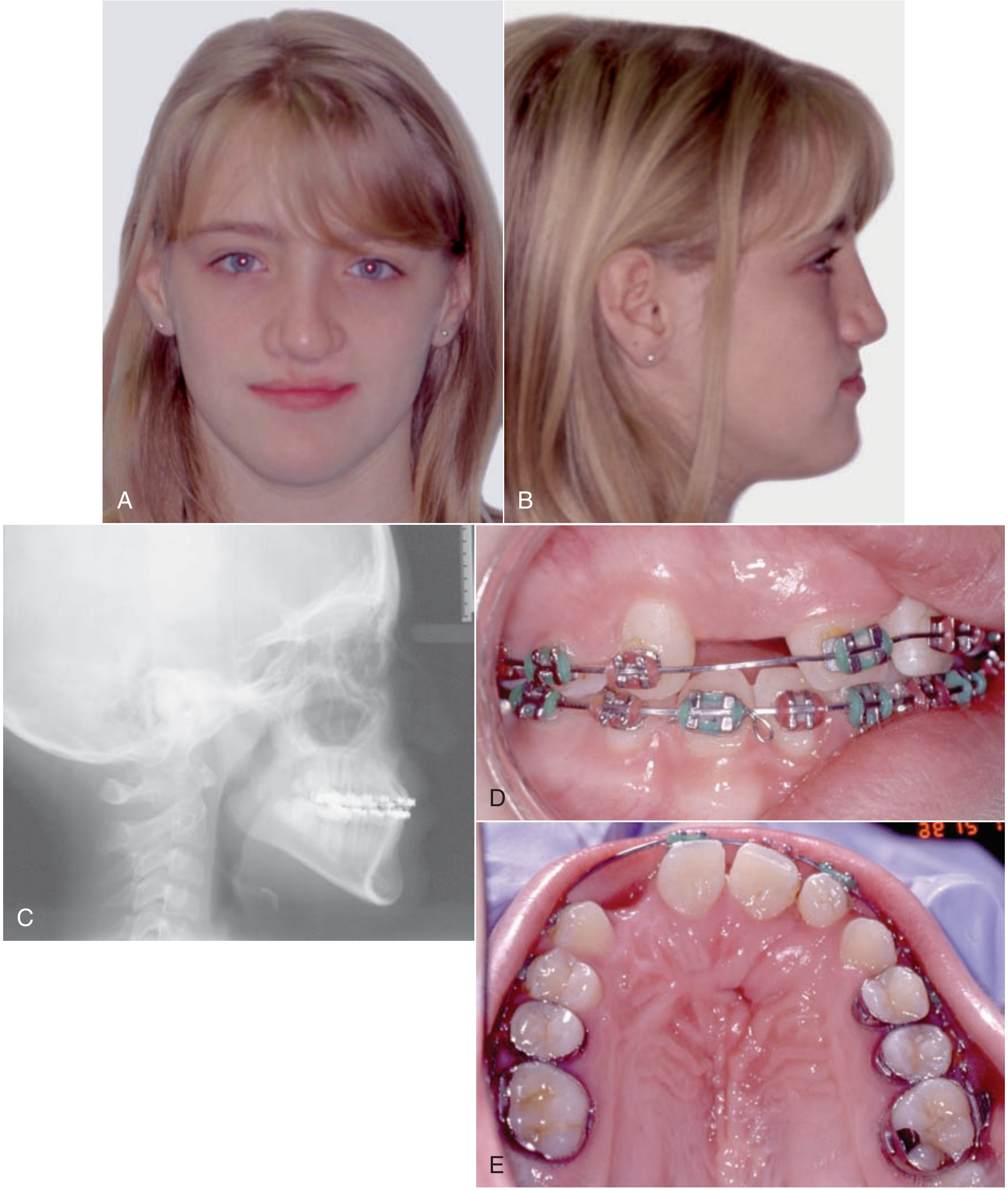

FIGURE 26-19 **A,** Frontal view of 12-year-old girl with repaired bilateral complete cleft lip and palate. **B,** Profile view reveals a straight profile with mild midfacial deficiency. **C,** Lateral skull cephalogram during comprehensive orthodontic treatment with camouflage for stabilized skeletal discrepancy. Note the proclined maxillary incisors and upright mandibular incisors. **D,** Right buccal view showing Class I canine relationship and positive overjet and overbite. **E,** Occlusal view showing missing right lateral incisor and malformed left lateral incisor. *(Adapted from Lidral AC, Vig KWL: The role of the orthodontist in the management of patients with cleft lip and/or palate. In Wyszynski D, editor:* Cleft lip and palate: from origin to treatment*, New York, 2002, Oxford University Press.)*

surgical procedure. If the skeletal discrepancy is mild and aesthetic concerns are minimal, dental compensation by orthodontic treatment alone may be recommended. A change in axial inclination of the teeth may camouflage the skeletal relationship adequately (see Figures 26-19 to 26-21). However, one should be cautious because the individual may outgrow the dental correction so that ultimately orthognathic surgery is indicated. The presurgical phase of orthodontic treatment requires decompensation of the dentition so that the maxillary and mandibular teeth are placed in their correct relationship to the underlying skeletal bases. If orthodontic therapy has achieved the ideal relationship of the teeth to the maxillary and mandibular skeletal bases, surgical

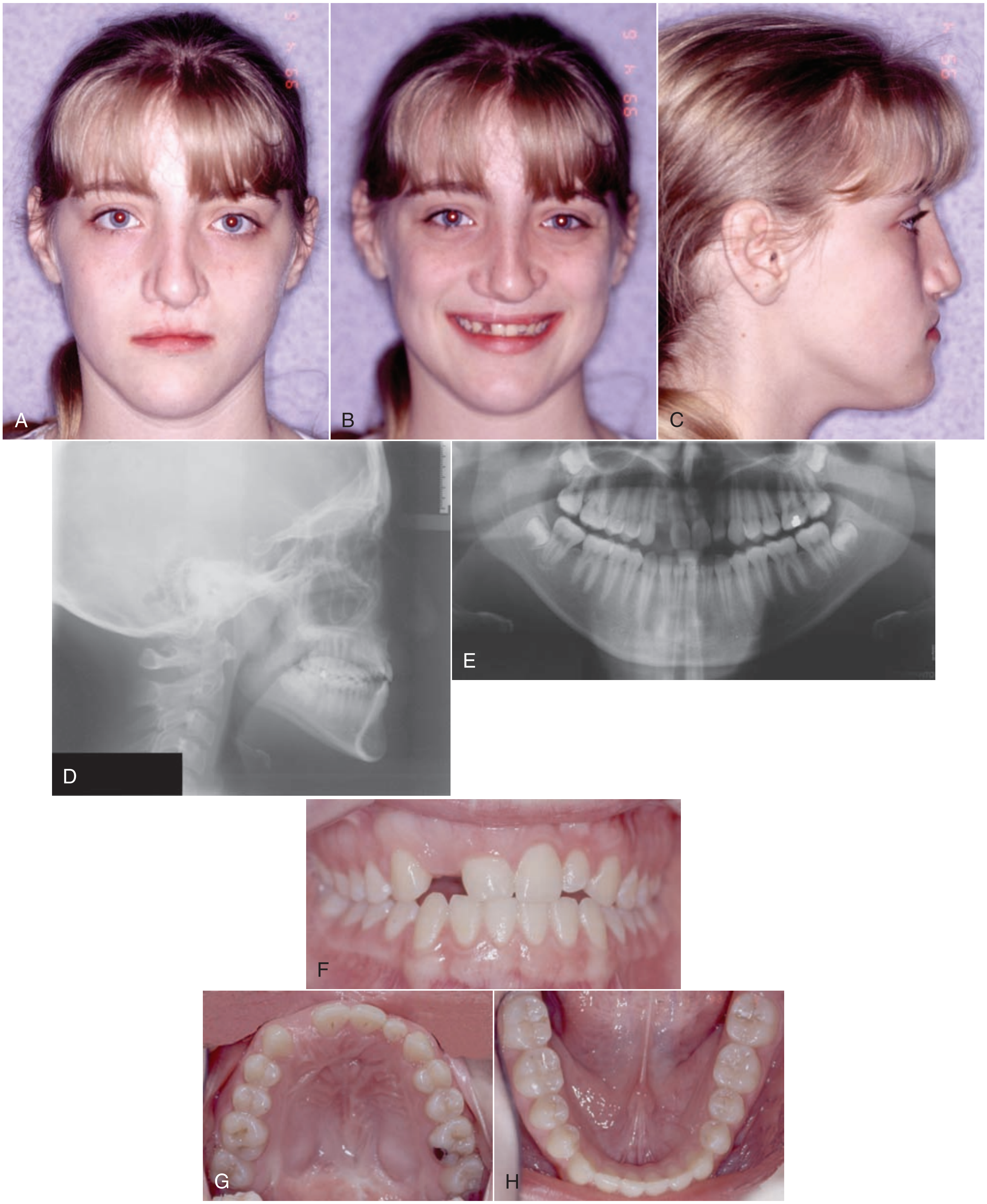

FIGURE 26-20 **A,** Same patient as in Figure 26-19 shown at 15 years of age in late adolescence following nose and lip revisions. **B,** Facial view of patient smiling. Note the symmetry of the upper lip in function. The patient is satisfied with the facial and dental outcomes. **C,** Profile facial view showing mild midface deficiency and paranasal flattening. **D,** Lateral skull radiograph demonstrating Class I camouflaged occlusion. **E**, Panoramic radiograph with cleft site successfully bone grafted and adequate space for implant placement to replace the congenitally missing lateral incisor. **F,** Intraoral view showing Class I incisal relationship with some overbite reduction. **G,** Maxillary occlusal view demonstrating closure of palatal oronasal fistula and adequate bony ridge depth for implant replacement of the missing lateral incisor. **H,** Mandibular occlusal view illustrating a well-aligned and symmetric arch form. *(Adapted from Lidral AC, Vig KWL: The role of the orthodontist in the management of patients with cleft lip and/or palate. In Wyszynski D, editor:* Cleft lip and palate: from origin to treatment, *New York, 2002, Oxford University Press.)*

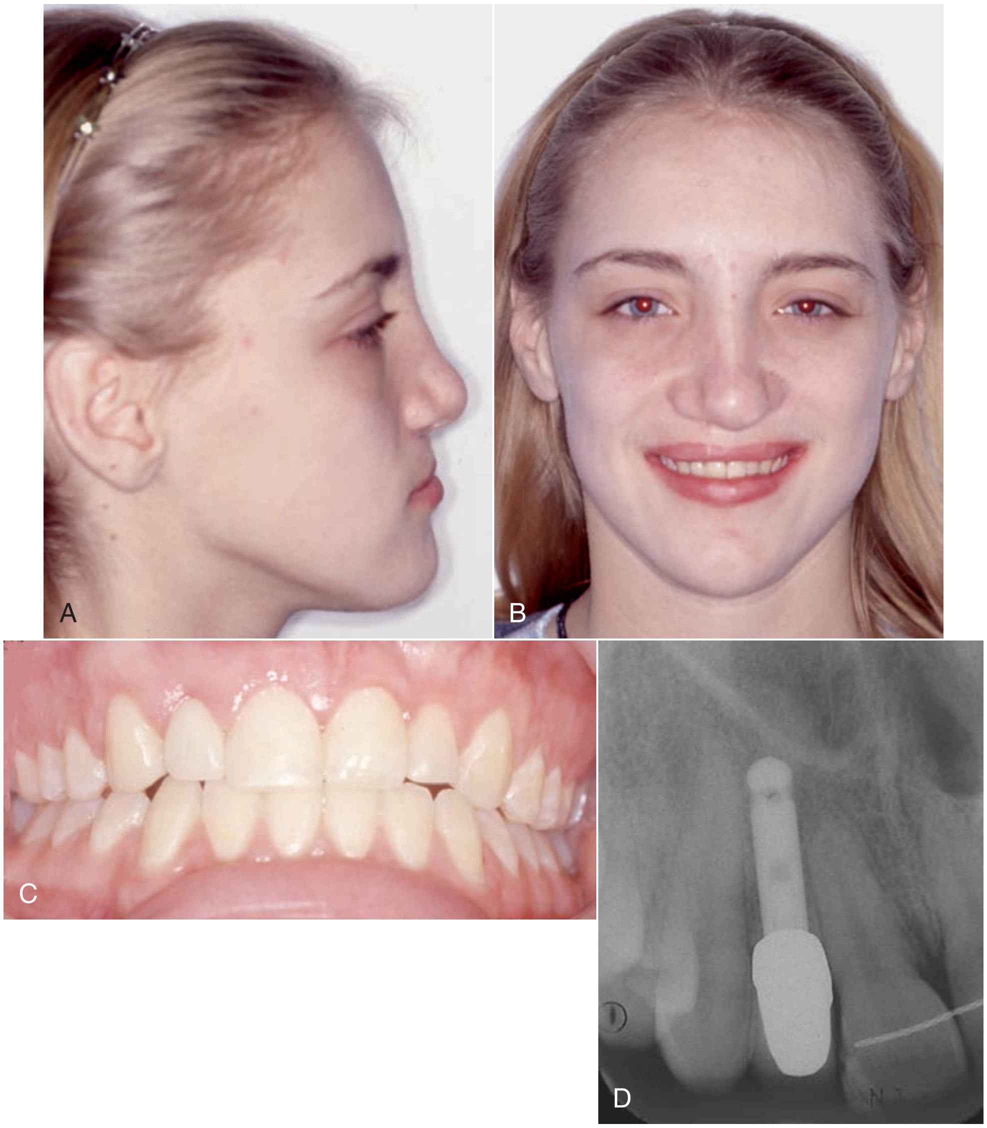

FIGURE 26-21 **A,** Same patient as in Figures 26-19 and 26-20 shown at 16 years of age. Note stability of skeletal relationship. **B,** Smiling view after prosthodontic treatment with implant for tooth No. 7 and cosmetic bonding of tooth No. 10. **C,** Intraoral view of prosthodontic treatment combined with gingivoplasty to restore the soft tissue contours for an improved tooth display and better gingival symmetry. **D,** Periapical radiograph showing complete osseointegration of implant prosthesis in the former site of the cleft alveolus. *(Adapted from Lidral AC, Vig KWL: The role of the orthodontist in the management of patients with cleft lip and/or palate. In Wyszynski D, editor:* Cleft lip and palate: from origin to treatment*, New York, 2002, Oxford University Press.)*

movements will result in the dentition and the maxilla and mandible being optimally related. In the past with conventional orthognathic surgery techniques for patients with severe maxillary hypoplasia, surgeons would advance the maxilla as much as possible in the presence of the scar tissue from the lip and palate repairs. The remaining skeletal discrepancy would be corrected with a mandibular setback. Essentially, this was a surgical camouflage of the inability to correct the underlying maxillary hypoplasia predictably (Figures 26-22 and 26-23). Additionally, the velopharyngeal mechanism may be compromised by maxillary advancement, especially if a pharyngeal flap has been already performed to improve speech.

Orthognathic Surgery. ***Treatment Planning.*** The timing and sequencing of treatment require close collaboration of the team. The decision to delay surgical orthodontic treatment until growth is stabilized may be sound but not always in the patient's best interest, especially when psychosocial development is affected. In some instances, skeletal surgery may be indicated before growth is completed, knowing that another procedure may be necessary if the patient outgrows the correction. As a general rule, skeletal surgery, orthodontic intervention, and final prosthetic rehabilitation should be completed before final soft tissue nose and lip revisions or rhinoplasty are instituted. The outcome of soft tissue surgical revisions, combined with osteotomies for the

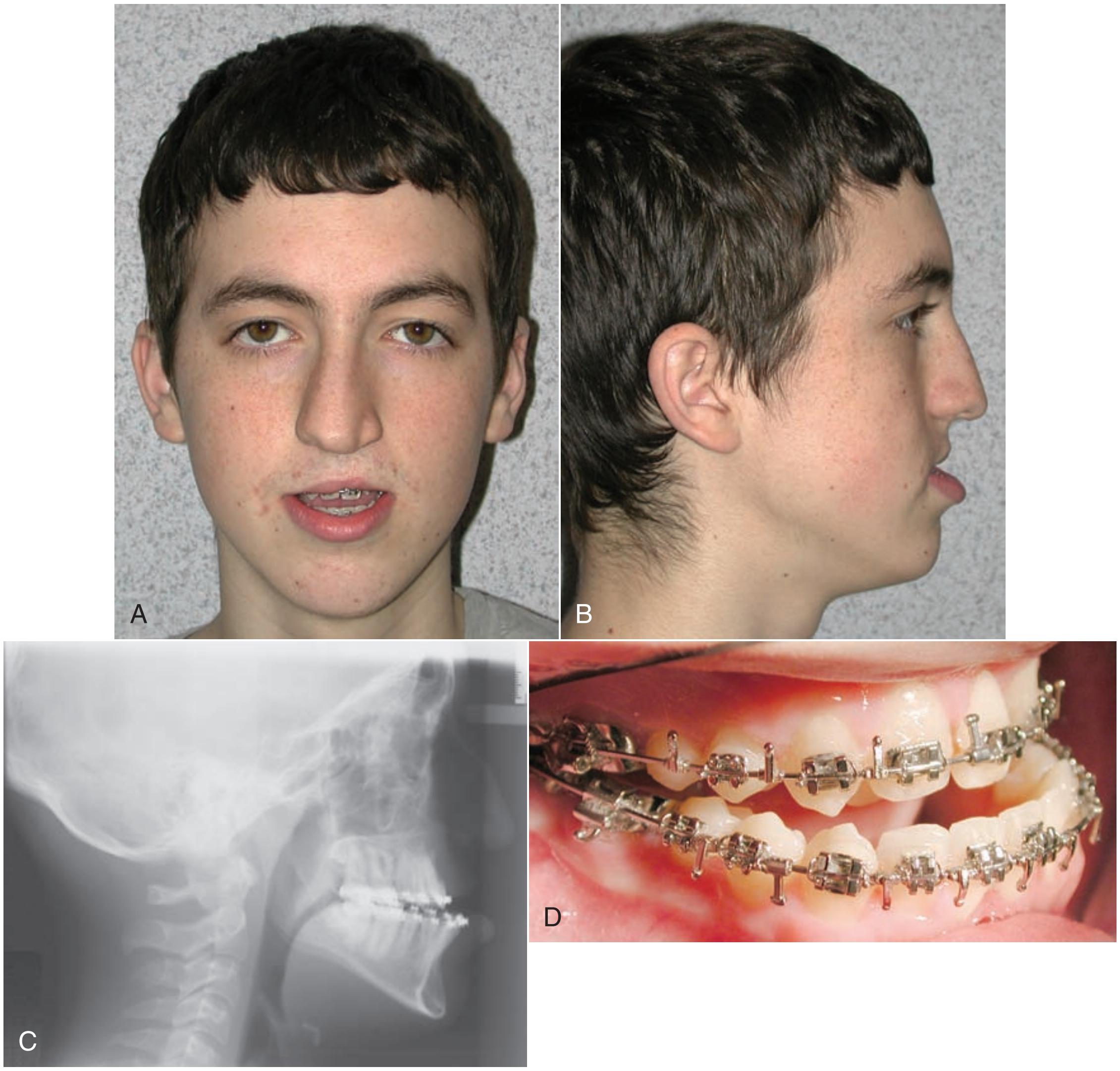

FIGURE 26-22 **A,** Frontal view of same patient as in Figures 26-16 and 26-17 shown at 16 years of age during presurgical orthodontic treatment for dental decompensation. **B,** Profile view reveals significant maxillary deficiency. **C,** Lateral skull radiograph shows the Class III skeletal pattern with maxillary and mandibular incisors in near corrected angulation within their respective apical bases. **D,** Right intraoral view shows leveled and aligned arches with negative overjet and surgical arch wires with lugs in place. Maxillary right lateral incisor is located palatally and will be extracted at time of surgery.

mobilization of the maxilla and mandible, is often unpredictable until the skeletal discrepancy has been corrected.

Role of the Orthodontist. A coordinated approach to the presurgical phase of orthodontic treatment is indicated. Twelve to 18 months of presurgical orthodontics are usually necessary to align the teeth, correct any compensations in axial inclination of teeth and any dental midline discrepancy, coordinate arches, and localize space for prosthetic replacement of the teeth. The provision of space for surgical cuts between the crown and the roots of adjacent teeth is also an important part of the presurgical preparations. Ideally, the patient is referred to the surgeon for a presurgical consultation, and the surgical movements are performed on mounted dental casts. Close communication between the surgeon and the orthodontist should identify any occlusal discrepancies that may prevent coordination of arches. The placement of full-size edgewise arch wires, with lugs, provides a means of intermaxillary fixation at the time rigid internal fixation is performed. After surgery is completed, the postsurgical phase of orthodontics details the occlusion, which should be completed within 4 to 6 months.

Distraction Osteogenesis. With the advent of distraction osteogenesis, correction of severe maxillary hypoplasia solely by advancing the maxilla may be possible.[62–64] Such correction would be accomplished by expansion of the scar tissue at the same time distraction osteogenesis is performed. Distraction osteogenesis is a relatively new treatment procedure that currently has few long-term follow-up studies reported. Moreover,

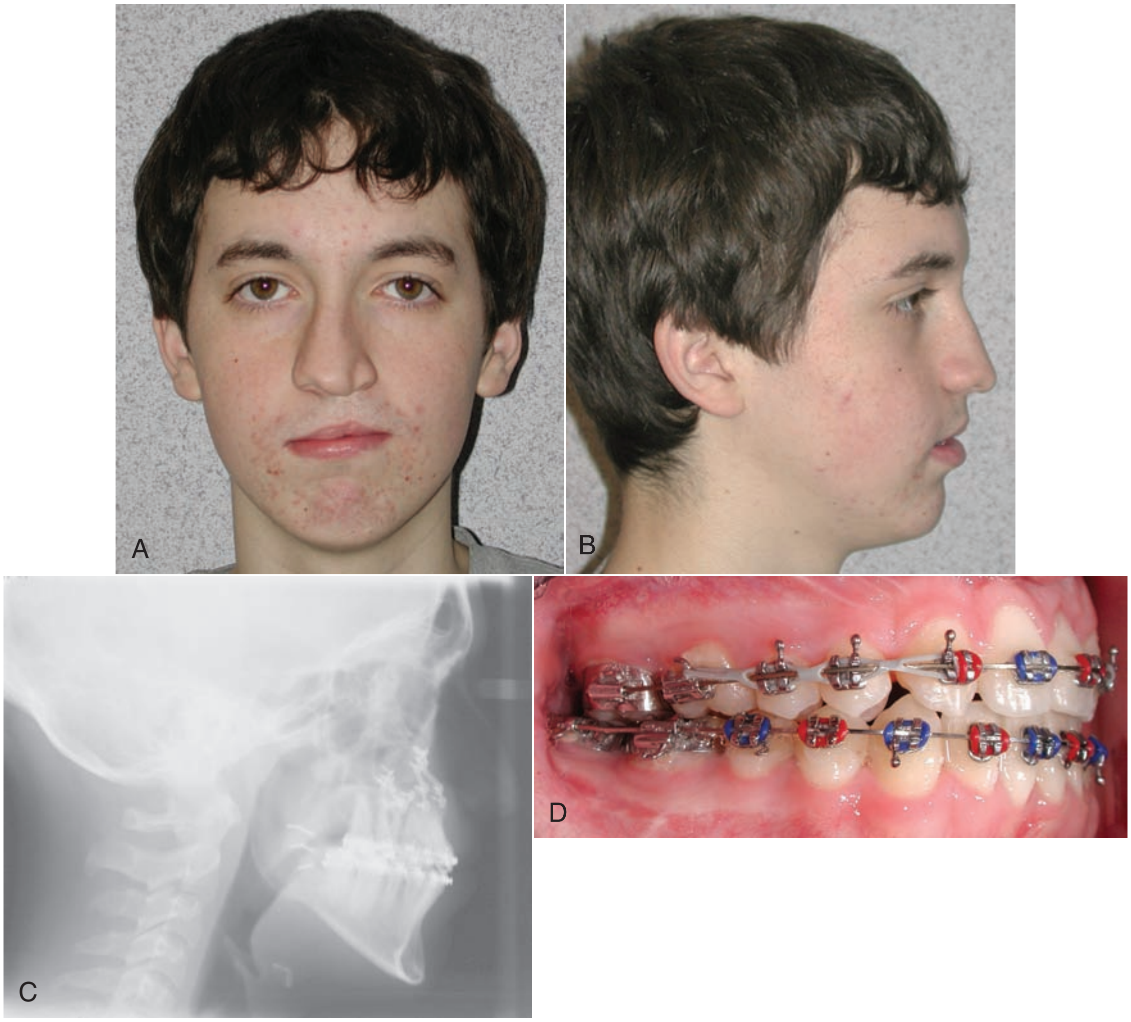

FIGURE 26-23 **A,** Frontal view of same patient as in Figure 26-22 shown at 17 years of age following maxillary advancement and mandibular setback surgery and undergoing postsurgical orthodontic treatment. Nasal asymmetry will be corrected with rhinoplasty. **B,** Profile view shows an improved profile and good upper lip support. **C,** Lateral skull radiograph shows adequate relationship of maxilla and mandible. **D,** Right intraoral view shows adequate overbite and overjet while orthodontically detailing the occlusion into a Class II molar. After recontouring and cosmetic bonding, the maxillary canines will substitute for the lateral incisors.

technologic advancements make comparisons difficult because bidirectional appliances have replaced unidirectional appliances, and internal and biodegradable appliances are replacing the original external devices. The predictability of the result in the young child by the time of adolescence also may suggest a conventional osteotomy to detail the occlusion because of the imprecise nature of the early appliances in controlling the direction of the maxilla during distraction. Nevertheless, the benefit of distraction osteogenesis in a hypoplastic maxilla with scar tissue and a compromised blood supply lies in a more gentle skeletal advancement with corticotomy cuts without downfracture of the maxilla (Figure 26-24). The orthodontist may monitor for hypernasal speech that could occur with advancement of the maxilla. Because the nasomaxillary complex is advanced slowly, at a millimeter per day, speech may be evaluated at intervals as the advancement proceeds and adaptation of the velopharyngeal mechanism occurs. Again, the treatment benefits need to be weighed against the burden of care and considered in the context of the scientific evidence of the probability of achieving quantifiable outcomes of success and failure.[65,66]

SUMMARY

The orthodontist's role in the cleft palate team requires close collaboration with the other team members. The rationale of timing and sequencing of orthodontic treatment have been discussed in four periods of development: (1) neonatal or infant maxillary orthopedics, (2) orthodontic considerations in the primary dentition, (3) mixed dentition to include presurgical considerations before an alveolar bone graft is placed, and (4) final treatment in the permanent dentition with orthodontics only or combined with orthognathic surgery. The latter

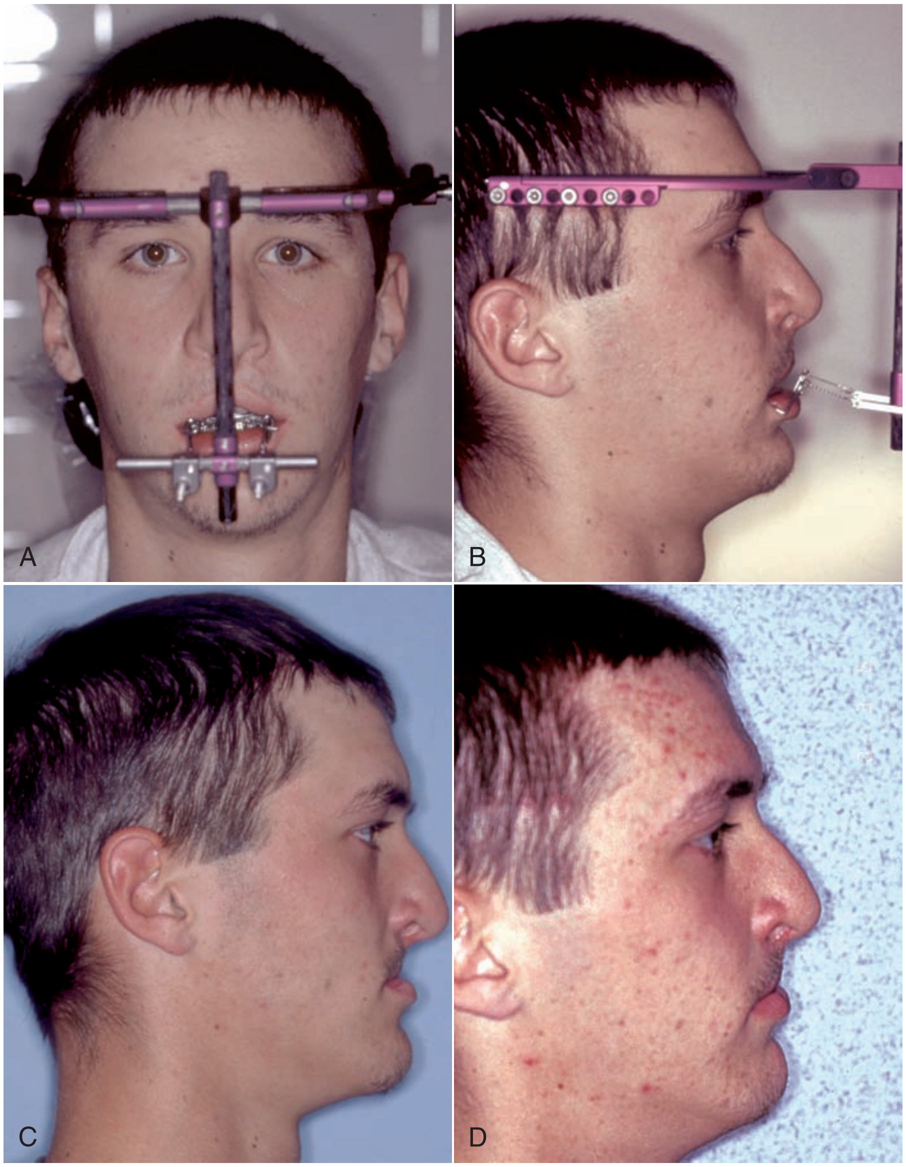

FIGURE 26-24 **A,** Frontal view of 19-year-old man with repaired bilateral complete cleft lip and palate, with rigid external distractor apparatus in place. **B,** Profile view with distraction osteogenesis appliance for advancement of the maxilla. **C,** Profile view before distraction osteogenesis. Note severe maxillary deficiency. **D,** Profile view after distraction osteogenesis. Note improved position of maxilla relative to mandible.

period combines an orthodontic and surgical approach to the correction of dental and skeletal components of malocclusion and facilitation of any necessary prosthodontic treatment. Speech considerations and the communicative skills of the patient with a cleft are important aspects in planning orthognathic surgery for these patients. Subsequent nose and lip revisions for cosmetic improvement must not be underestimated in the enhancement of the final soft tissue facial aesthetic result following correction of the skeletal and dental discrepancies. Provided that the team members plan the timing and sequencing of appropriate treatment modalities in a closely coordinated, problem-oriented approach, patients with clefts should have optimal functional and aesthetic results. Outcome measures for reporting the results of surgical interventions require the choice of valid and reliable measures to be identified and implemented.[65,66] The ultimate outcome for team-based care is to have a fully rehabilitated patient who is satisfied with the treatment outcomes in terms of speech, occlusion, facial and dental aesthetics, and function. The patient should continue to receive conventional dental and medical routine evaluations similar to any adult to maintain optimal oral health.

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CHAPTER 27

Stability, Retention, and Relapse

Donald R. Joondeph

OUTLINE

History of Retention
  The Occlusion School
  The Apical Base School
  The Mandibular Incisor School
  The Musculature School
Basic Retention Theorems Proposed in the Literature
  Theorem 1
  Theorem 2
  Theorem 3
  Theorem 4
  Theorem 5
  Theorem 6
  Theorem 7
  Theorem 8
  Theorem 9
Case Reports
Tooth Size Discrepancies
  Proximal Reduction of Tooth Width
  Axial Inclinations
  Transverse Discrepancies
  Relationship of Third Molars
  Growth Factors
  Gender Differences
  Further Implications of Growth
  Recovery from Tooth Movements
Clinical Applications of Retention
Retention Appliances
The Positioner in Retention Planning
Duration of Retention
Recovery after Relapse

A working definition of retention in relation to orthodontics might be stated as follows: The holding of teeth in optimal aesthetic and functional positions.

The requirements for retention often are decided at the time of diagnosis and treatment planning. The correct problem list or diagnosis, a logical treatment plan, and the timing of the treatment must be directed toward achievement of favorable aesthetics, ideal function, and the permanent maintenance of these ideals. A satisfactory balance of utility, beauty, and stability can often minimize the need for retention by mechanical appliances. However, incorrect diagnosis or treatment complicates the requirements for retention. For instance, gross expansion of the dental arches, severe changes in arch form, incomplete correction of anteroposterior malrelationships, and uncorrected rotations may require indefinite retentive measures.

Teeth that have been moved through bone by mechanical appliances have a tendency to return to their former positions. Orthodontists have long been aware of this fact and the purpose of retention, in general, is to counteract this tendency (see Chapter 5).

The type of retentive measures and the duration of their use allegedly are determined by how many teeth have been moved and how far,[1] the occlusion and age of the patient,[2] the cause of a particular malocclusion, the rapidity of correction,[3] the length of cusps and health of tissues involved, relationships of the inclined planes,[4,5] size of the arches or arch harmony, muscular pressure, approximal contact, cell metabolism, and atmospheric pressure.[6]

Historically, authors have suggested the following with regard to retention in general:

1. Rotation should be corrected by overrotation in the opposite direction.[7]
2. Elastics should be worn continuously.[8]
3. Retention should depend on a fixed type of appliance.
4. Retention should depend on modification of structure and function of tissues.[9]
5. Slight movement is more difficult to retain than extensive movement.[10]
6. Occipital retention is most desirable for certain cases.[11]
7. Treatment should be correlated with development.
8. Function is the most important factor in retention.
9. Appliances should be removable[12] and not depend on teeth for retention.[13]

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10. Overcorrection of all malpositions should be attempted.
11. Retention depends on bone change, which in turn is related to endocrine dysfunction.
12. Functional adaptation of occlusion occurs with growth.
13. Retention is a problem of the apical base or apical base limitations.[14]
14. Mandibular incisors should be maintained upright over basal bone.[15,16]
15. Discrepancies in tooth sizes may cause problems in retention.[17]
16. Early treatment is more desirable than treatment at a later age.[18]
17. Intercanine and intermolar widths should be maintained as in the original malocclusion.[19]
18. An attempt at functional treatment (i.e., to achieve muscle balance) is desirable.
19. Use of mild forces is desirable.
20. Limitations to moving teeth are imposed on the orthodontist by the arch itself.[20]

HISTORY OF RETENTION

For many years clinicians did not agree about the need for retention. Hellman[21] said in summary, “We are in almost complete ignorance of the specific factors causing relapses.” Different philosophies or schools of thought have developed, and present-day concepts generally combine several of these theories.

The Occlusion School

Kingsley[22] stated, “The occlusion of the teeth is the most potent factor in determining the stability in a new position.” Many early writers[2,4,5,9,10,23–33] agreed that proper occlusion was of primary importance in retention.

The Apical Base School

In the middle 1920s, a second school of thought formed secondary to the writings of Axel Lundström,[14] who suggested that the apical base was one of the most important factors in the correction of malocclusion and maintenance of a correct occlusion. McCauley[34] suggested that intercanine width and intermolar width should be maintained as originally presented to minimize retention problems. Strang and Thompson[35] further enforced and substantiated this theory. Nance[36] also noted that “arch length may be permanently increased only to a limited extent.”

The Mandibular Incisor School

Grieve[15] and Tweed[16,37] suggested that the mandibular incisors must be placed and kept upright and over basal bone.

The Musculature School

Rogers[38] introduced a consideration of the necessity of establishing proper functional muscle balance. Others corroborated this theory. Orthodontists have come to realize that retention is not separate from orthodontic treatment but that it is part of treatment itself and must be included in treatment planning. Hellman[21] aptly described it:

> Retention is not a separate problem in orthodontia but is a continuation of what we are doing during treatment. It is not a definite stage of treatment requiring a new technique; therefore, there is no need for a separate machinery to carry it through. Retention is but a letting off of what we have been doing during treatment. The changes that we do make in our machinery are to ease up on the strains and stresses and to wean the tissues away from the effects of all our tinkering so that any change that is made should be a reduction in appliance. This can be done by changing either the type of the appliance or the amount of time wearing it. A complete result must be accomplished before retention is applied.

Stability has become a primary objective in orthodontic treatment, for without it ideal function, optimum aesthetics, or both may be lost.[39] Retention depends on what is accomplished during treatment. One must exercise care to establish a proper occlusion within the bounds of normal muscle balance and with careful regard to the apical base or bases available and the relationships of these bases to one another.

BASIC RETENTION THEOREMS PROPOSED IN THE LITERATURE

Theorem 1

Teeth that have been moved tend to return to their former position.[39–41] Experts do not agree on the reason for this tendency. Suggested influences include morphogenetic pattern musculature,[42] apical base,[43–45] transseptal fibers,[46] and bone morphology. Regardless of the reason, most clinicians agree that teeth should be held in their corrected positions for some time after changes are made in their position. Only a few orthodontists have suggested that retention is routinely not necessary.[27,47]

Theorem 2

Elimination of the cause of malocclusion will prevent recurrence.[36] Until more is known about the causative factors that are related to particular types of malocclusion, little can be done about their elimination. When obvious habits such as thumb or finger sucking or lip biting are contributors to a malocclusion, it is much easier to recognize them as etiologic factors. Regarding retention, however, preventing recurrence of the causative factors for a given malocclusion is important. One of the most insidious habits that operates against satisfactory retention is tongue posture and function, which results in anterior and occasionally lateral open bites. The mere fact that the patient has been directed along a course of tongue therapy and has been able to meet all the exercise requirements of the therapist on conscious command does not guarantee correction.[20]

In fact, several authors have suggested that open bite malocclusion may be due to mouth breathing resulting from nasopharynx obstruction that could result from anatomic blockage, allergic disease,[40] or adenoid hyperplasia.[48] Mouth breathing could also be habitual, which then necessitates a compensatory low anterior tongue posture and rotated mandibular position for the individual to be able to breathe. Indeed, changes in mandibular posture seen in patients with sleep apnea could be a factor in open bite development even after orthodontics has been completed. Dentofacial changes associated with this functional alteration appear to become more severe with age[40] and are a challenge to diagnose accurately and to treat and retain successfully. This retention problem has been discussed by Lopez-Gavito et al.,[43] who conducted a long-term evaluation of patients with initial anterior open bites. The authors found that despite attempts to control posterior maxillary vertical changes during appliance therapy and retention, 35% of the patients who presented with an initial open bite had an open bite of 3 mm or more 10 years after retention.

Theorem 3

The malocclusion should be overcorrected. A common practice of many orthodontists is to overcorrect Class II malocclusions into an edge-to-edge incisor relationship. Orthodontists must be aware, however, that these over-corrections may be the result of overcoming muscular balance rather than absolute tooth movement. The unrestricted use of Class II elastics sometimes produces a mesial postural displacement of the mandible, which is almost impossible to detect until elastics have been discontinued long enough to allow normal mandibular posture to return. Quessenberry,[49] however (using full-time intermaxillary coil springs), suggests that, although often difficult, the most retruded mandibular position, centric relation, can be determined and duplicated after release of Class II mechanics. He also found that Class II forces tended to have a greater effect on tooth position than on jaw position.

Although less likely, the same phenomenon may be seen in the use of Class III elastic forces. The use of elastics must be likened to the use of traction forces in orthopedic surgery, in which muscular forces are overcome by constant pull. However, absolute overcorrection is possible and has been demonstrated in many instances. Overcorrection of deep overbite is an accepted procedure by many clinicians. Certainly, satisfactory maintenance of overbite correction depends on the establishment of satisfactory correction during treatment.

One of the most common types of relapse is the tendency for a previously rotated tooth to attempt movement toward its former position. Overrotation is often not practical and, furthermore, little evidence exists to indicate that it is successful in preventing return to the initial relationship. Preventing the anterior teeth from erupting in a rotated position is often possible by providing space for them to erupt unimpeded by use of orthodontic expansion appliances or by the early extraction of primary teeth. As Reitan has shown, the principle is that if the tooth had never been rotated initially, it certainly would have less tendency to rerotate at a later time.[7,50] Also, increased stability of corrected rotations through minor surgical intervention has been recommended by Allen,[51] Boese,[52] Brain,[53] and Edwards (transeptal fibrotomy).[54]

Theorem 4

Proper occlusion is a potent factor in holding teeth in their corrected positions.[55] From the standpoint of reducing the potential of irritation to the periodontium, an excellent functional occlusion is certainly desired. Orthodontists often blame hyperfunction or "pounding" of the mandibular canines by the maxillary canines for relapse in the mandibular anterior area.[56] On the other hand, the wear that many teeth undergo without secondary movement suggests that they do not necessarily move in response to normal grinding and tapping. Movement may occur however when supporting bone has been lost and it does not prevent the migration of teeth or when fibrous tissue builds up to such a degree that it actually moves the teeth and makes correct function of these teeth impossible. Certainly, instances of mandibular anterior irregularity or collapse are common, in which canines have not yet erupted or are not actually in occlusion. Studies evaluating the stability of the mandibular arch[43] show no difference in long-term postorthodontic change between patients with anterior tooth contact compared with individuals with anterior open bite malocclusions devoid of canine contact in centric relation and functional excursions. Orthodontists too often consider the denture from a static viewpoint (e.g., with the teeth in occlusion as seen on nonarticulated study casts) rather than functionally, and although the final functional occlusion is an extremely important treatment objective, it is not clear if proper intercuspation is the most important factor in retention.

Theorem 5

Bone and adjacent tissues must be allowed to reorganize around newly positioned teeth. In general, the orthodontist should use some type of fixed or removable retention appliance to maintain the correction achieved. Histologic evidence shows that the alveolar bone and periodontal ligament around teeth that have been moved are altered and considerable time elapses before complete reorganization occurs. Some authors have said that retainers should be fixed, such as the "G wire,"[1] the band-and-spur type of attachment,[57] and bands soldered together. Other authors believe that retainers should be only inhibitory and should have no positive fixation to allow for the natural functioning of teeth; it has been suggested that the mandibular lingual arch admirably suits this description.[7,58] Oppenheim[13] argued that appliances should only be inhibitory and that repair of tissues around the teeth occurs much more rapidly if no fixed retaining appliance is used.

All these suggestions are based on the presumption that mature bone will ensure greater stability for the teeth. Present day orthodontic concepts, however, regard bone as being a plastic substance and consider tooth position to result from an equilibrium of the muscular forces and transeptal and periodontal fibers surrounding the teeth.[59] The placement of retentive appliances, then, may be an admission of inadequate orthodontic correction or of a predetermined decision to place teeth in relatively unstable positions for aesthetic reasons. Whether stability increases with prolonged retention is one of the most interesting points of discussion regarding retention planning and is the phase of treatment that is most difficult to quantify. Documentation and control of variables such as cooperation, length of retention time, growth, and appliance design make this type of investigation difficult to interpret.

Theorem 6

If the lower incisors are placed upright over basal bone, they are more likely to remain in good alignment. Accordingly, one should direct attention to the proper angulation and placement of the mandibular incisor segment.[15,16,60–63] Obviously, the difficulty of evaluating this theorem revolves around proving that incisors have been placed upright over basal bone. The term "upright" is definable: perpendicular to the mandibular plane, 5 degrees or some other specified angulation to the occlusal plane or Frankfort horizontal plane. However, no one can specify where basal bone begins or ends, and there seems to be no satisfactory method of measuring it.[45,64–66]

Teeth that are upright have sometimes been assumed to also be over basal bone. However, in certain cases the roots of mandibular incisors have been moved labially to a considerable degree in the process of uprighting these teeth. Significantly, many malocclusions present with mandibular incisors upright and over basal bone, and yet these teeth are crowded and rotated. Teeth that supposedly have these attributes of stability can actually be in a state of malocclusion (Figure 27-1).

If the patient is growing, the mandibular anterior segment may exhibit a physiologic migration or eruption pattern in relation to the mandibular body in a distal direction that is apart from orthodontic treatment.[67–70] One can readily see that if the mandibular anterior segment is moved lingually during orthodontic treatment, this movement may be in harmony with the normal expected migration of these teeth; hence, retentive care may be minimized.[71] Mandibular arch form, however, may play a more important role in stable mandibular tooth alignment than does the relative anteroposterior relationship of mandibular denture to base.

Theorem 7

Corrections carried out during periods of growth are less likely to relapse. Orthodontic treatment, therefore, should be instituted at the earliest possible age. Little direct evidence substantiates this statement, but it is plausible. If orthodontists are in any way able to influence growth in development of the maxilla or mandible, then certainly one may presume logically that this growth can be influenced only while the patient is growing.[18,72–74] In 1924, Matthew Federspiel[75] said, "I am free to confess that we find it almost impossible to treat a true type of disto-occlusion without extraction after the developmental period and keep it in position." When treatment depends on an inhibition or alteration of direction of growth, as implied in headgear or functional appliance therapy, treatment must be instituted sufficiently early to utilize periods of active growth (see Chapter 14).

Early diagnosis and treatment planning appear to afford several advantages in long-term stability. Institution of early treatment can prevent progressive, irreversible tissue or bony changes,[76] maximize the use of growth and development with concomitant tooth eruption, allow interception of the malocclusion before excessive dental and morphologic compensations (which may become more difficult to treat and retain than the primary malocclusion symptom); and allow correction of skeletal malrelationships while sutures are morphologically immature and more amenable to alteration.

Theorem 8

The farther teeth have been moved, the less likelihood there is of relapse. Thus, when it has been necessary to move teeth a great distance, the patient probably will need less retentive attention.

Possibly, positioning teeth far from the original environment produces equilibrium states permitting more satisfactory occlusions, but the wisdom of this rule has not been confirmed. Little evidence supports the statement that the farther teeth have been moved, the less relapse tendency they will have. In fact, the opposite is likely true! Iatrogenic damage such as root resorption is also more likely to occur as a result of long treatment times and extensive tooth movement. It may be more desirable to minimize the need for future extensive tooth

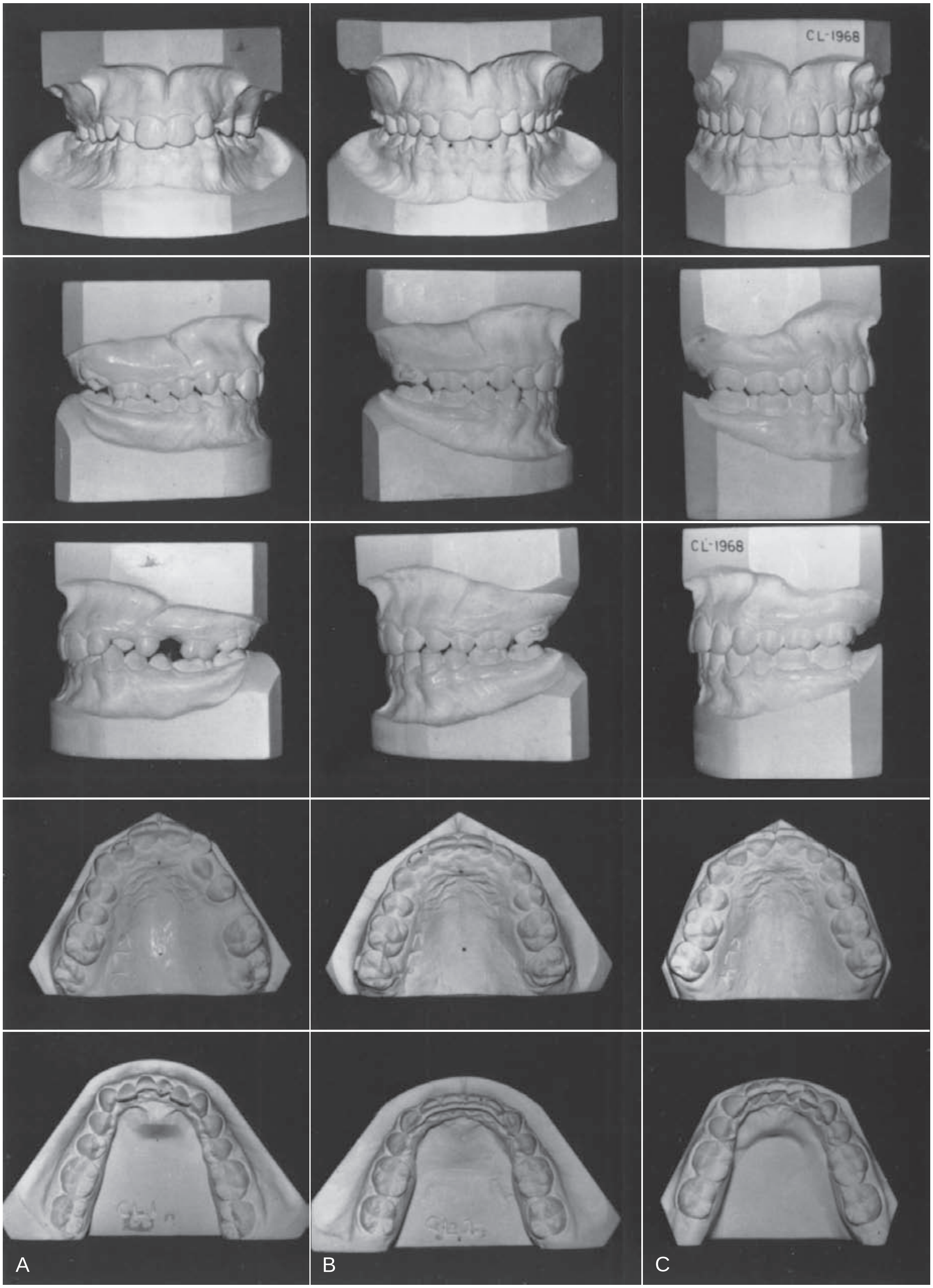

FIGURE 27-1 Mandibular incisor crowding, first treated without extraction. Treatment was completed later with the extraction of four second premolars. The mandibular anterior area continued to show incisor irregularity after retention was discontinued, as evidenced by the mandibular occlusal study model taken at age 30 years 5 months. Whether stability of mandibular incisor alignment could have been achieved with any form of treatment is doubtful. **A,** Before treatment, age 12 years 4 months. **B,** After treatment, age 14 years 7 months. **C,** More than 15 years after retention, age 30 years 5 months.

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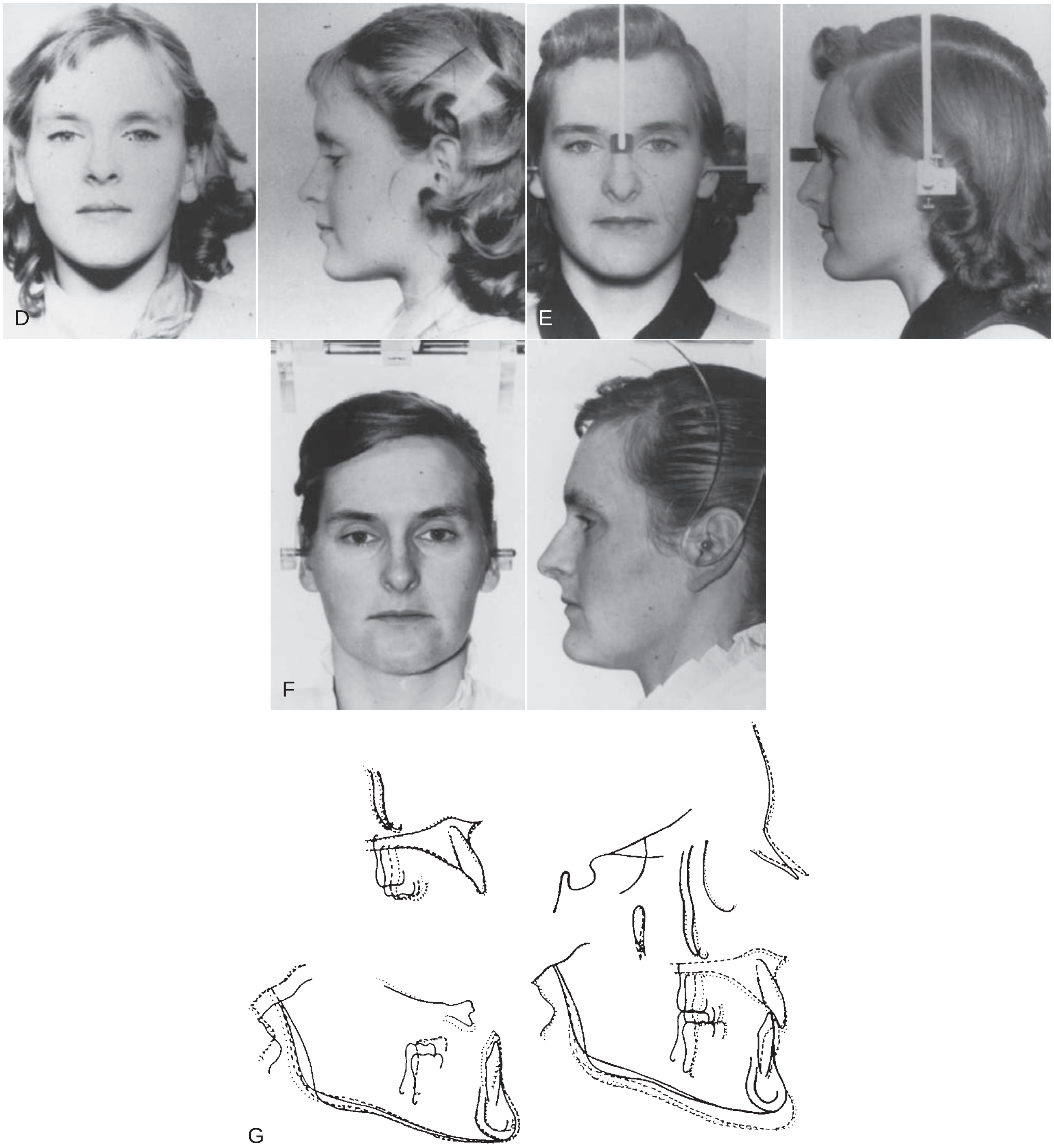


FIGURE 27-1, cont'd **D–F,** Note the improved facial aesthetics at the three intervals. **G,** Tracings before treatment (*solid line*), after treatment (*dashed line*), and at age 30 years 5 months (*dotted line*).

movement through guidance of eruption and early interception of skeletal discrepancies.

Theorem 9

Arch form, particularly in the mandibular arch, cannot be altered permanently by appliance therapy. Therefore treatment should be directed toward maintaining the arch form presented by the malocclusion as much as possible.[35] The evidence brought to the author's attention by Nance[36] and others that attempted to alter mandibular arch form in the human dentition and generally met with failure has been accepted as a treatment guideline by many orthodontists. In 1944, McCauley[34] made the following statement: "Since these two mandibular dimensions, molar width and canine width, are of such an uncompromising nature, one might establish them as fixed quantities and build the arches around them."

Strang[35] said essentially the same thing in 1946:

> I am firmly convinced that the axiom of the mandibular canine width may be stated as follows: The width as measured across from one canine to the other in the mandibular denture is an accurate index to the muscular balance inherent to the individual and dictates the limits of the denture expansion in this area of treatment.

CASE REPORTS

A number of investigations of orthodontically corrected malocclusions several years after retention have been made by various authors.[41,77] In almost every instance, mandibular intercanine width tended to return to the original dimension after all the retaining appliances had been removed for several years. One of the few postretention case reports that seems to conflict with the theorem of the relative stability of intercanine width is that of Walters,[20,78] who described maintaining slight increases in mandibular intercanine width after all retention had been removed for what he termed an "adequate period." Arnold[79] also pointed out that at least 5 years must elapse following discontinuation of retention appliances before an apparent maintenance of increased intercanine width can be accepted. In one of his patients, the intercanine width was increased by 4.2 mm during treatment. After 1 year without retention, there was a contraction of 1 mm, so that the gain in intercanine width was still 3.2 mm. However, after a 5-year postretention period, an overall effective intercanine width gain of only 0.7 mm was measured (Figure 27-2).

During the same year, Amott[80] conducted an examination of patients out of retention whose malocclusion had been treated without the extraction of any permanent teeth. The results of this investigation also indicated that, with the exclusion of an exceptional case in which 5.7 mm of intercanine width increase was maintained for 7 years (Figure 27-3), the postretentive intercanine widths were similar to or the same as pretreatment intercanine dimensions. Riedel[81] reported previously on several groups of patients who were at least 5 years out of retention and whose mandibular intercanine widths had returned to their original dimensions. Similar and stronger evidence regarding the inability to maintain increased intercanine width has been found in cases 10 years out of retention[82] (see Chapter 5).

One frequent suggestion has been that if the mandibular canines are moved into a more posterior, wider

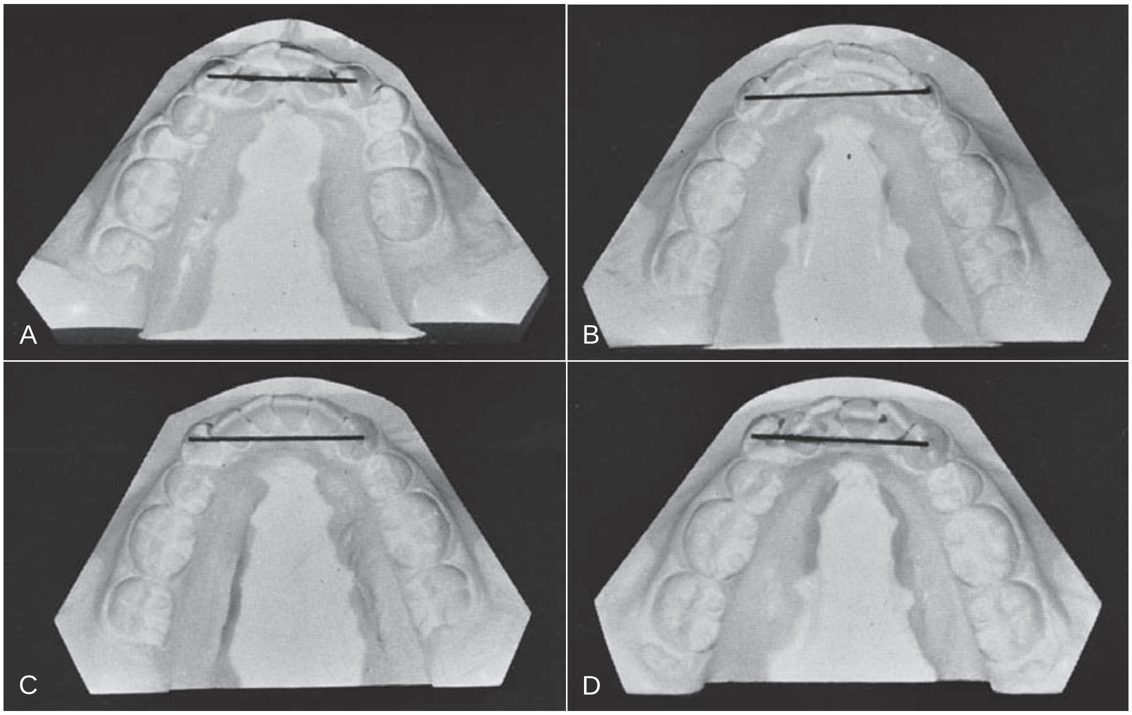


FIGURE 27-2 **A,** Malocclusion. **B,** After completion of treatment. **C,** After 1 year out of retention. **D,** After 5 years out of retention. Intercanine widths: before treatment, 24.2 mm; after treatment, 28.4 mm; 1 year postretention, 27.4 mm; 5 years postretention, 24.9 mm. Note that after 1 year without retention there had been a contraction of only 1 mm, yet after 5 years the total intercanine gain was 0.7 mm. This illustrates the distorted conclusion, based on a 1-year postretention period rather than one of 5 years, that would be drawn regarding the amount of posttreatment adjustment in this case. *(From Arnold M: A study of the changes of the mandibular intercanine and intermolar width during orthodontic treatment and following a five or more years postretention period, master's thesis, Seattle, 1962, University of Washington.)*

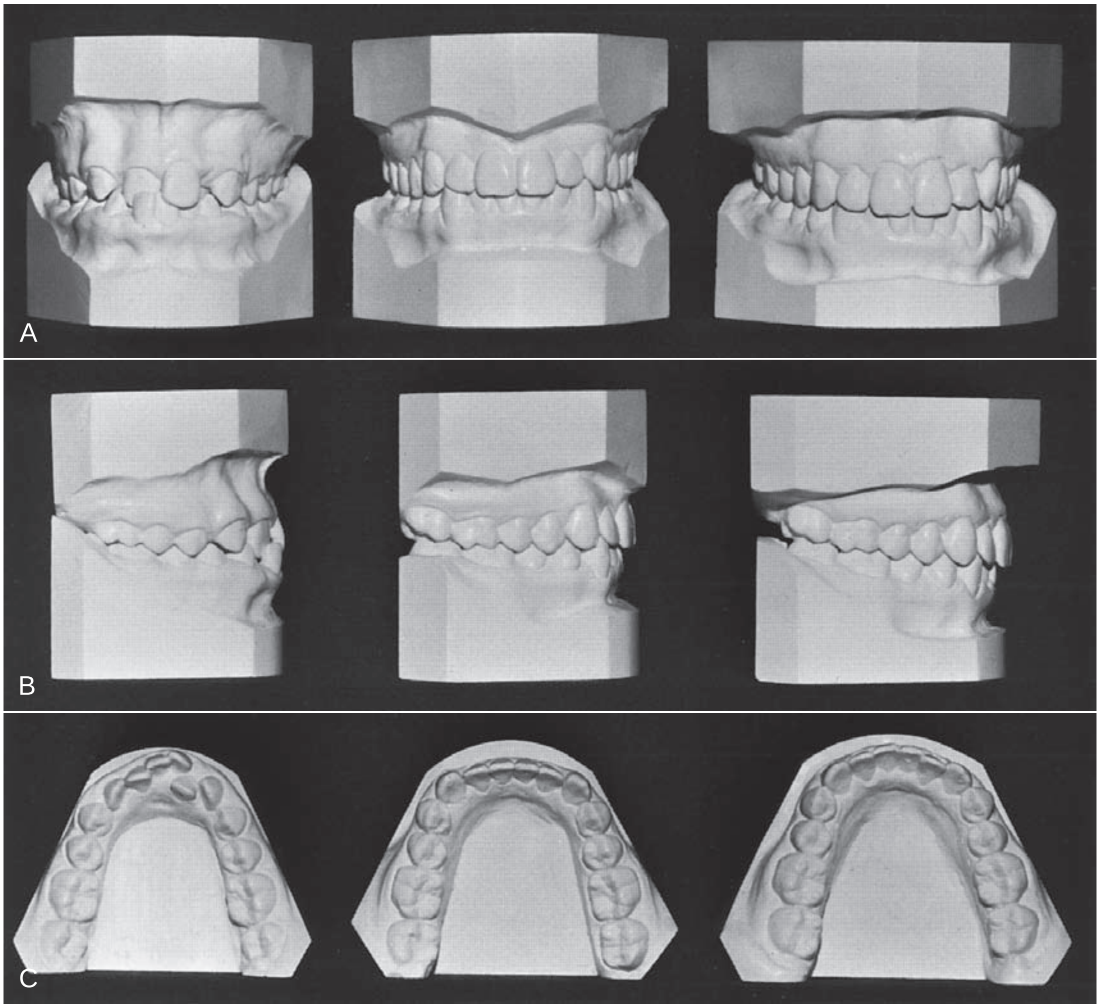


FIGURE 27-3 Case 1. **A,** Before treatment, after treatment, and 7 years after retention (*left* to *right*). **B, C,** Before treatment, after treatment, and postretention (7 mm of expansion held). *(From Amott RD: A serial study of dental arch measurements on orthodontic subjects, master's thesis, Chicago, 1962, Northwestern University.)*

position in relation to the mandibular basal arch, increased intercanine width can be expected to hold. Although this seems logical, all the evidence collected to date indicates that distal mandibular canine movement, whether by tipping or bodily repositioning, has little to do with increasing intercanine width and correlates poorly with degree of incisal crowding (Figure 27-4).

The following are some of Arnold's conclusions[79]:

1. The intercanine width in patients who had no retaining devices for a period of 5 years or more shows a remarkable tendency to return to or approach that of the original malocclusion.
2. No significant effect on resultant intercanine width is demonstrated after premolar extraction therapy.
3. The original intercanine width, when it is intelligently and judiciously used, can serve as a valuable clinical guide to orthodontic diagnosis and treatment (Figure 27-5).

Further evidence is provided by Dona,[83] Little et al.,[84] Shapiro,[85] and Welch.[42] Little et al.[84] examined patients treated with first premolar extraction and routine edgewise mechanics at least 10 years out of retention and stated that long-term alignment was variable and unpredictable. They found that no descriptive characteristics (e.g., Angle class, length of retention, age at initiation of treatment, or gender) or measured variables (initial or end-of-active-treatment alignment, overbite, overjet, arch width, or arch length) were of value in predicting long-term stability. Arch width and length typically autonomously decreased after retention, whereas crowding was increased. This occurred despite treatment maintenance of initial intercanine width or treatment expansion or constriction. Their conclusion was that success in maintaining satisfactory mandibular anterior alignment is less than 30%, with nearly 20% of the cases likely to show crowding many years after removal of retainers.

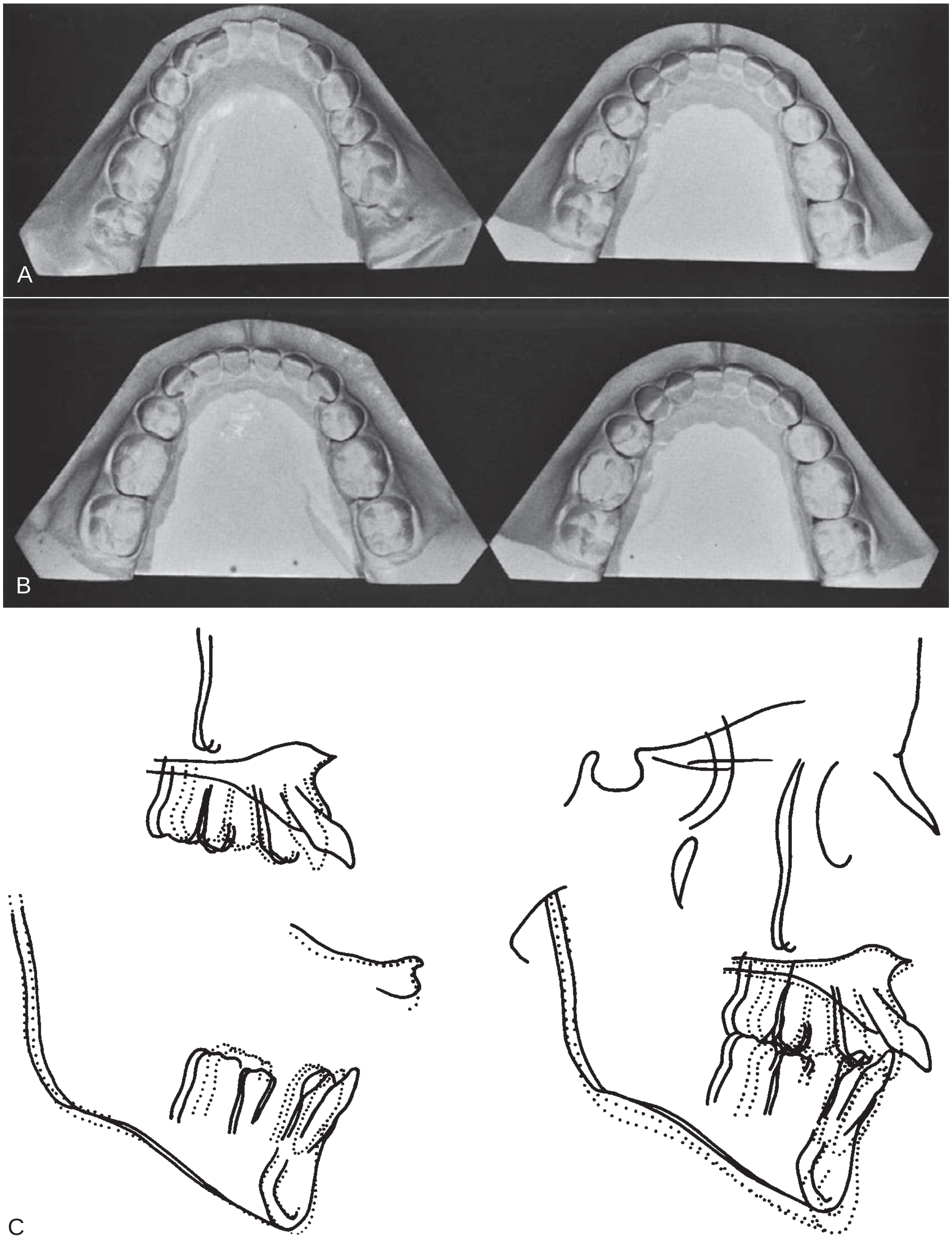


FIGURE 27-4 A, Pretreatment (*left*) and 3 weeks after the lower retainer was lost (*right*). Intercanine width has decreased to within 0.5 mm of the original dimension. **B,** At the time lower retainer was placed (*left*; canines expanded 4 mm at the end of treatment) and 3 weeks later (*right*; canines contracted almost to original width). **C,** Definite distal movement of the mandibular canines between pretreatment and posttreatment models.

Also evaluating a 10-year postretention sample, Shields et al.[86] studied the relationship of cephalometric changes to mandibular incisor alignment and found that combinations of pretreatment and posttreatment cephalometric parameters (e.g., incisor position and facial growth) were poor predictors of long-term mandibular incisor stability. Additionally, the postretention changes in cephalometric measurements failed to explain postretention crowding.

The exact number of years out of retention provides no certainty relative to the stability of arch alignment. Witness the case represented in Figure 27-6 before

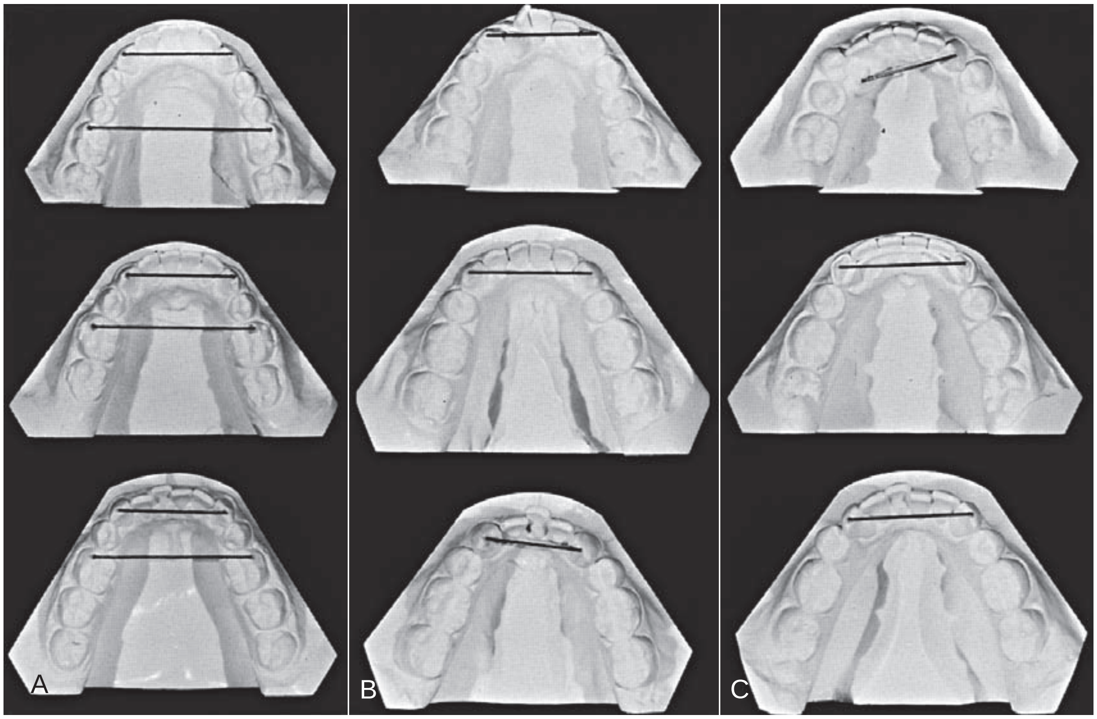


FIGURE 27-5 **A,** Premolar extraction. Measurement across the canines and molars before extraction (*top*), after extraction (*middle*), and after retention (*bottom*). Note the incisor irregularity after retention, despite maintenance of the pretreatment intercanine width and extraction of the premolars. **B,** Postretention variability. Intercanine widths were 26.7 mm before treatment (*top*), 29.3 mm after treatment (*middle*), and 23 mm after retention (*bottom*). The patient lost an incisor in an accident, but the remaining incisors are crowded despite premolar and incisor extraction and reduced intercanine width. **C,** Postretention variability with an effective increase in intercanine width. The measurement was 23.8 mm before treatment (*top*), 29.5 mm after treatment (*middle*), and 27.4 mm 5 years after retention (*bottom*). Note that the left canine was lingually impacted, leading to an effective intercanine gain of 3.6 mm. Measurement from R3 to L4 (before treatment) is almost the same as from R3 to L3 after retention.

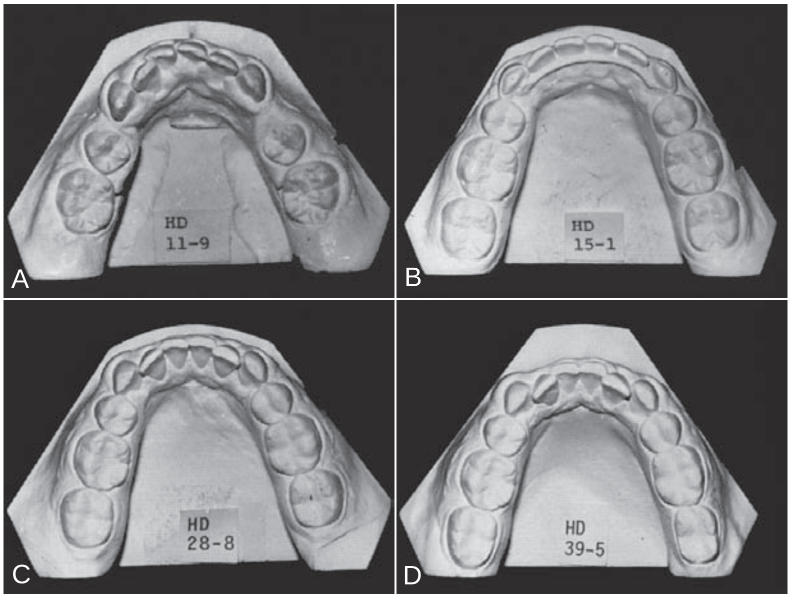


FIGURE 27-6 Case 2. **A,** Before treatment (age 11 years 9 months). **B,** After treatment (age 15 years 1 month). **C,** After 10 years out of retention (age 28 years 8 months). **D,** After 25 years out of retention (age 39 years 5 months). Note the increase in mandibular incisor crowding between the 10- and 20-year postretention records.

treatment, after treatment, 10 years postretention, and 20 years postretention. Further crowding took place between 10 and 20 years out of retention. This is only one of many cases to exhibit postretention changes of various degrees.

Two of Shapiro's conclusions[85] are important additions to the knowledge of postretention changes: (1) Class II, Division 2 malocclusions demonstrated a significantly greater ability to maintain intercanine width expansion compared with Class I and Class II, Division 1 treated malocclusions, and (2) arch length reduction in Class II, Division 2 was significantly less than in Class I and Class II, Division 1 during treatment and from pretreatment to 10 years postretention.

TOOTH SIZE DISCREPANCIES

A discrepancy in tooth size is an often overlooked problem in retention. Ballard[87] reported that 90% of the casts of 500 patients he examined had tooth size discrepancies. When maxillary anterior teeth are too large in relation to mandibular anterior teeth, the maxillary teeth must be placed in one of the following positions: (1) deeper overbite, (2) greater overjet, (3) combinations of greater overbite and overjet, (4) crowded anterior segment, or (5) out of proper occlusion buccal segment (the maxillary teeth fitting into a more or less distal relation with the mandibular because the posterior teeth generally do not remain stabilized in an end-to-end occlusion).

If the mandibular anterior teeth are too large, compensations can include (1) an end-to-end incisor relationship, (2) spacing in the maxillary anterior segment, (3) crowding in the mandibular incisor area, or (4) improper occlusion distal to and including the maxillary lateral, with the maxillary posterior teeth in mesial relation to the mandibular posterior teeth. Estimating and determining these discrepancies are possible by making a trial diagnostic setup or using a mathematical formula that can determine the degree and the location of a tooth size discrepancy between maxillary and mandibular arches.[77] Three-dimensional imaging allows a very precise means of direct tooth size measurement and resultant planning for inherent discrepancies.

Proximal Reduction of Tooth Width

One can make measurements of all orthodontic casts and/or digital images before consultation appointments and determine tooth size ratios noting the degree and location of abnormality of a discrepancy. When anterior tooth size discrepancies exceed 2.5 mm in patients whose teeth are otherwise normally formed (excluding pegged or undersized maxillary lateral incisors), a trial setup usually is indicated. If the teeth can only be occluded in a normal relationship with interproximal tooth size reduction as determined by a trial setup, clinicians must include the "stripping" of these same teeth in the mouth. Interproximal "stripping" can typically be accomplished with more ideal control and ease during the finishing stages of therapy, albeit with proper diagnosis and treatment planning, the technique may be used to facilitate tooth movement.

Between 2 and 4 mm of enamel can be removed from the maxillary or mandibular six anterior teeth. Inclusion of the maxillary or mandibular first premolars also is occasionally desirable, especially when incisors have minimal interproximal taper. When tooth size discrepancies exceed this dimension, it is logical to consider some other type of approach to treatment, such as extraction of a single incisor, which usually is done in the case of an excess in the mandibular anterior segment (Figure 27-7). If an excess exists in the maxillary anterior segment, the greatest amount of enamel usually can be removed from the distal surfaces of the maxillary central incisors, maxillary lateral incisors, and maxillary canines. Occasionally the maxillary first premolars can be trimmed at the mesial surface. Enamel thicknesses can be determined from good periapical radiographs. Removal of so much enamel from the contact area that crown width becomes narrower than the cervical dimension or the roots of the teeth themselves also is unwise, for then closure and maintenance of the spaces between the teeth in a normal contact relationship are unlikely, with the prospect of loss of interseptal bone, particularly in the lower incisor segment.

The procedure involved in stripping anterior teeth usually includes the use of "lightning" strips to break open contact areas, a limited use of "lightning" or diamond disks to reduce the greater bulk of enamel, and the completion of final polishing and recontouring with "lightning" strips as well as medium and fine sandpaper strips so that the original contour of the tooth crown can be reestablished and the tooth enamel kept smooth. If stripping is done by reducing one proximal surface at a time, visualization or measurement of the amount of tooth enamel removed is easier. If both surfaces in a proximal area are reduced at the same time using double-sided abrasion strips, determining which of the surfaces had the greater amount of enamel removed is difficult. If the clinician proceeds from right to left, removing 0.25 mm on all surfaces from the distal of one canine to the mesial of the contralateral tooth, the clinician then can reverse the procedure and remove another 0.25 mm starting from the distal of the left canine and moving to the mesial of the right. A total of 0.5 mm gained in each interproximal space reduces the tooth size discrepancy by about 2.5 mm. Significant amounts of interproximal tooth reduction should be done first on a diagnostic setup to evaluate the resultant occlusion and the amounts and locations should then be transferred clinically to the patient's dentition.

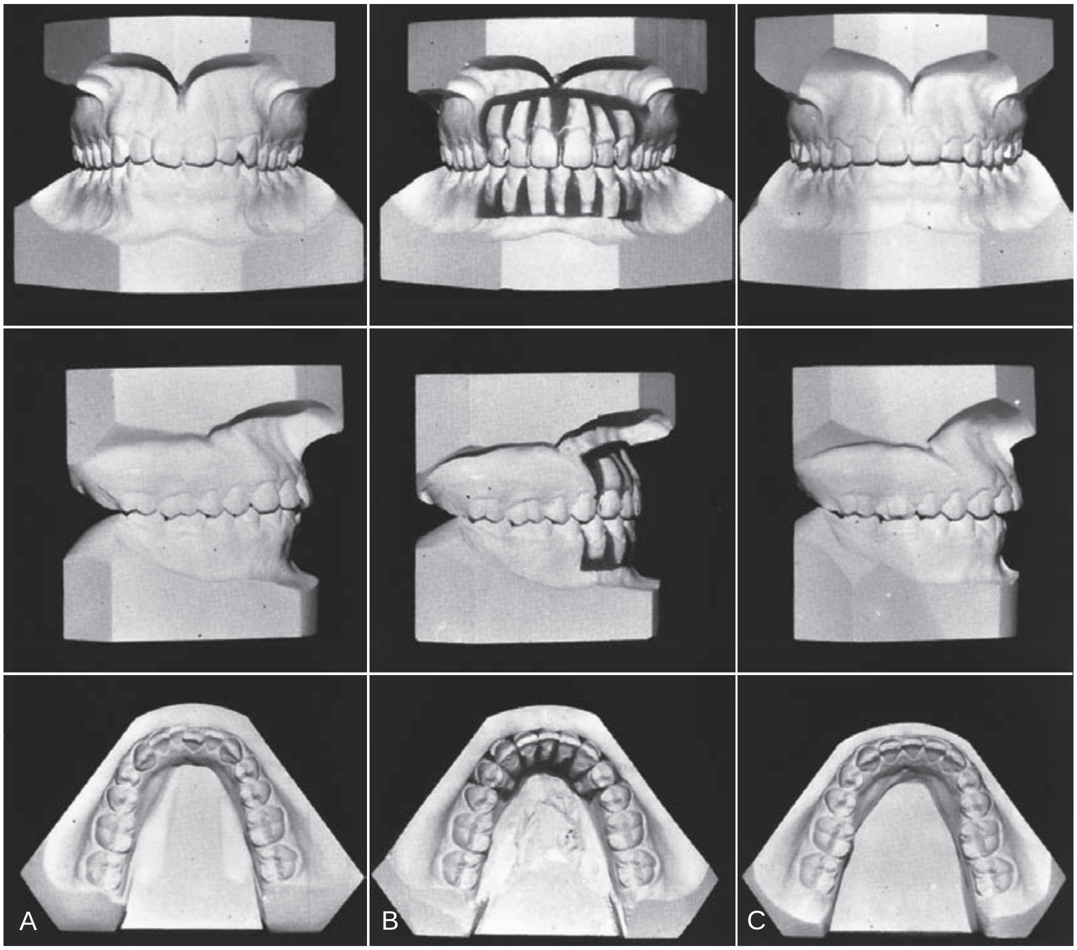


FIGURE 27-7 **A,** Before extraction of L1. **B,** Diagnostic setup showing the extraction, interproximal marking, and trimming of the maxillary anterior teeth. **C,** After extraction and treatment.

Axial Inclinations

Another consideration that is not frequently discussed in the orthodontic literature is the axial inclination of the maxillary and mandibular incisor teeth. In many instances, orthodontists are brought to the realization that the farther they have retracted mandibular incisors, the farther they must retract the maxillary incisors. Tipping maxillary and mandibular incisors into too upright a relation usually results in deep anterior overbite. Periodontists suggest that this type of occlusion has potentially damaging functional implications.[88] Bolton[48] found that in excellent occlusions, the angles of the labial surfaces of the maxillary and mandibular central incisors to their occlusal plane totaled about 177 degrees. In other words, the labial surfaces of these teeth in profile formed almost a straight line.

An interesting note is that the technique of measuring the axial inclinations of maxillary to mandibular anterior teeth is not really a satisfactory method from a functional standpoint. Drawing a line from incisal edge through root tip may be a convenient technique for determining axial inclination for cephalometric tracings, but it certainly does not take into account variations in crown-root relationships that exist. From an aesthetic viewpoint, measuring the relationship of the labial surfaces of the crowns of the anterior teeth is most desirable. From a functional standpoint, however, perhaps the angulation of the lingual surfaces of the maxillary anterior teeth and their relation to the labial surfaces of the mandibular incisors might be more important (Figure 27-8). Lingual anatomy is variable and should be evaluated as functional relationships are planned.

Transverse Discrepancies

Numerous authors[33,89–91] have documented the tendency for relapse associated with rapid palatal expansion techniques, particularly in the permanent dentition. Typically, the clinicians must significantly overcorrect in the transverse dimension, anticipating that a more normal relationship will occur during the postguidance stages. Additionally, the expansion appliance must be maintained passively for approximately 16 weeks followed by a removable retention appliance.

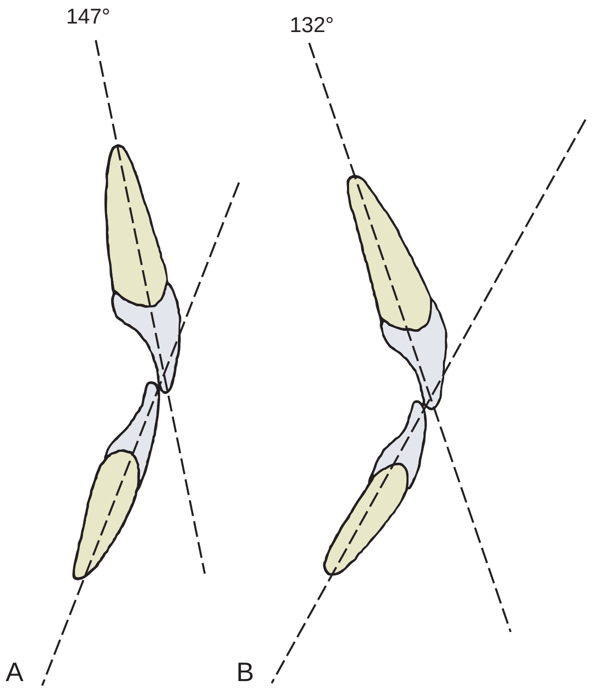


FIGURE 27-8 **A,** Axial inclinations of the maxillary and mandibular central incisors from an angle of 147 degrees. Labial surfaces of the crowns in profile meet at almost 180 degrees. **B,** The axial inclinations of the maxillary and mandibular incisors form an angle of 132 degrees, yet the crown surfaces are almost exactly in the same relative functional position as in **A.**

Storey[62] has documented experimentally that rapid expansion results in a predominantly destructive process in which the sutural connective tissue becomes disrupted and edematous, with enlarged blood vessels or hemorrhaging. This tissue eventually is "filled in" by immature bone as a healing response. The growth of bone of sufficient maturity requires a slow, steady rate of formation with lateral separation of bones on the order of 0.5 to 1.0 mm per week. Results of Storey's experiments show that slow separation with continued growth of mature bony serrations within the suture provides the best retention with the least potential for relapse.

Castro,[92] Cotton,[93] and Hicks[94] have evaluated further, experimentally and clinically, the stability of palatal expansion with light continuous forces and have concluded that this technique is more stable than rapid expansion.

Anatomically, the limitation of palatal expansion is not fusion of the midpalatal suture but rather changes in the morphology of the suture that take place once an individual stops growing and the suture becomes nonadaptive. As the patient matures, continued intercuspation and interdigitation of bony serrations take place until the suture becomes mechanically difficult to expand at older ages. These changes in sutural morphology may occur as early as 13 to 14 years in individuals who stop growing in that age range. Early expansion with light forces, achieved before these maturation changes can occur, allows maximal skeletal separation, with normal physiologic bone deposition enhancing the long-term stability in this plane of space.

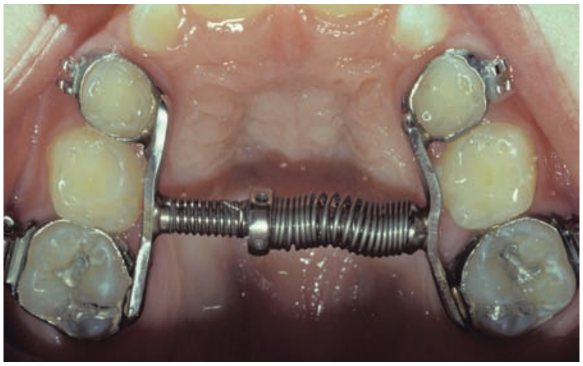


FIGURE 27-9 Miniexpander with a 2-psi compressed coil and a ligature wire tied adjacent to the turnscrew to maintain its position. The patient is seen once every 3 to 4 weeks.

Clinically the author uses a modified mini-expander in which a 2- or 4-psi coil is substituted. Coils are fabricated to deliver the desired force on full compression (Figure 27-9). In the author's experience, excellent clinical results are achieved using a 2-psi force when the patient is in the mixed dentition and a 4-psi force when the patient is in the permanent dentition. The clinical results achieved with this type of expansion procedure are illustrated in Figures 27-10 and 27-11.

Relationship of Third Molars

Although some authors[95–98] have attributed the presence of third molars to long-term mandibular dental stability, other investigators[99–102] have published data suggesting that third molars play little, if any, role in long-term mandibular arch changes.

Ades et al.[99] compared four groups of patients who were a minimum of 10 years out of orthodontic retention. Patients studied had one of the following bilateral mandibular third molar status: (1) third molars erupted into good alignment and function, (2) third molar agenesis, (3) third molar impaction, and (4) third molar extraction at least 10 years before postretention records. They found no differences in mandibular incisor crowding, arch length, intercanine width, and eruption patterns of mandibular incisors and molars between the groups. In the majority of cases, some degree of mandibular incisor crowding took place after retention but it was not statistically significantly different between third molar groups. This suggests that the recommendation for mandibular third molar removal with the sole objective of alleviating or preventing mandibular incisor irregularity may not be justified (Figure 27-12).

Text continued on page 1008

FIGURE 27-10 **A,** Age 9 years 4 months. Bilateral maxillary constriction and resultant mandibular functional shift to the left. **B,** After 8 weeks of expansion with a 2-psi force. Excellent axial control of the maxillary buccal segments. **C,** Appearance 2 years after expansion with no retention. Excellent stability.

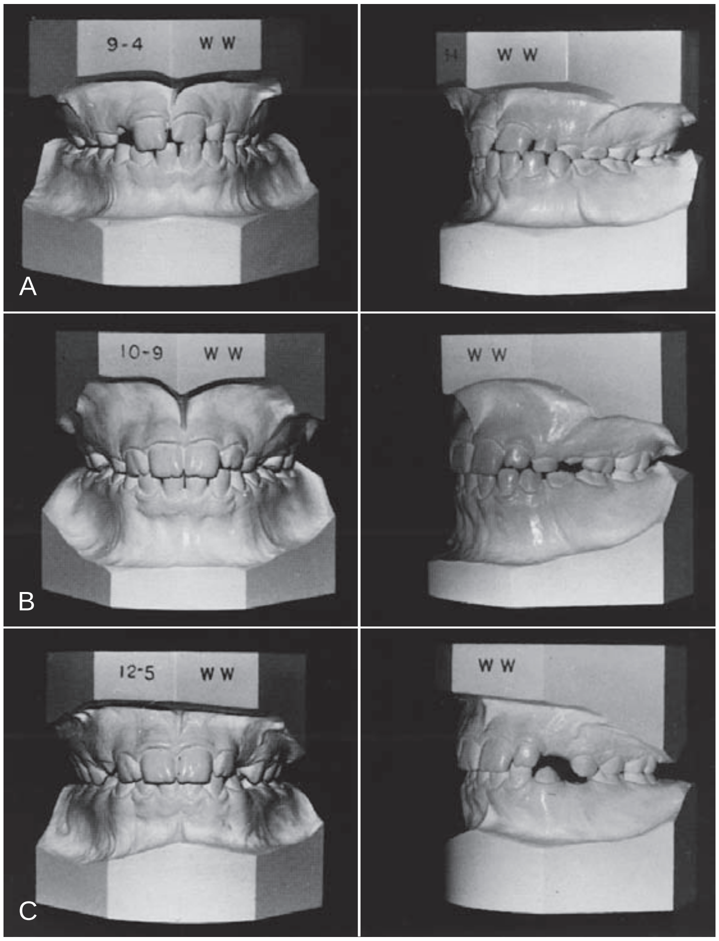
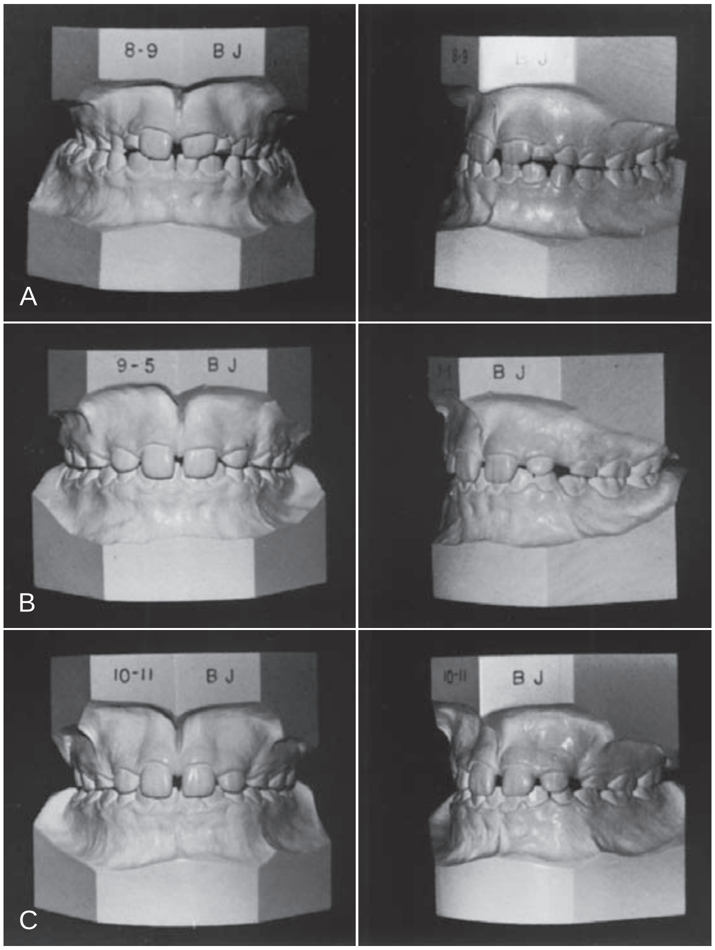


FIGURE 27-11 **A,** Age 8 years 9 months. Bilateral maxillary constriction has resulted in a bilateral maxillary lingual crossbite. **B,** After 10 weeks of expansion with a 2-psi force. Note the excellent axial control and the absence of bite opening. **C,** Appearance 18 months after expansion with no retention. Excellent stability is noted.



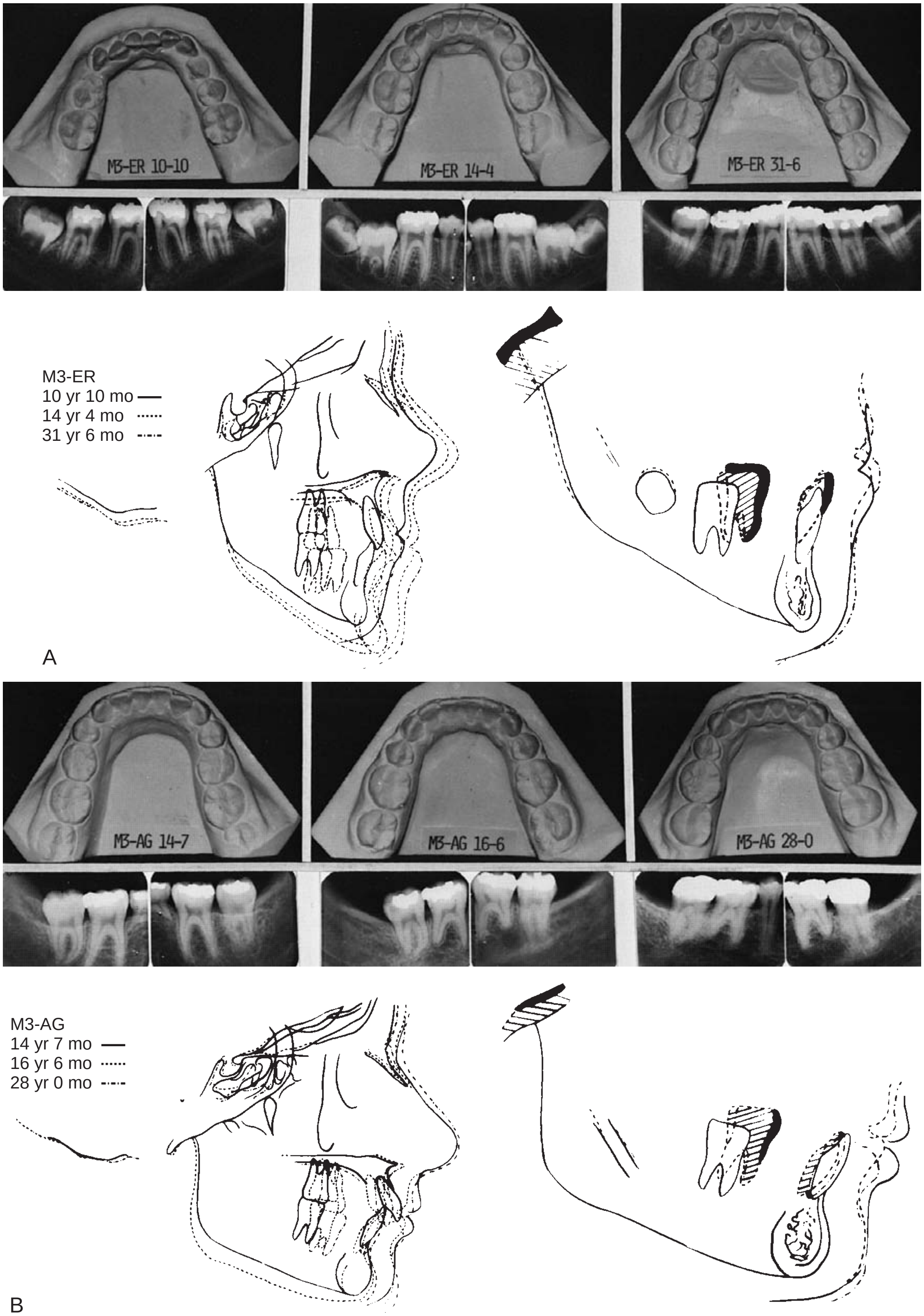


FIGURE 27-12 Study models and periapical radiographs (pretreatment, posttreatment, and postretention) plus overall and mandibular superimpositions of patients with the following: **A,** bilaterally erupted third molars (M3-ER); **B,** bilateral third molar agenesis (M3-AG). *Continued*

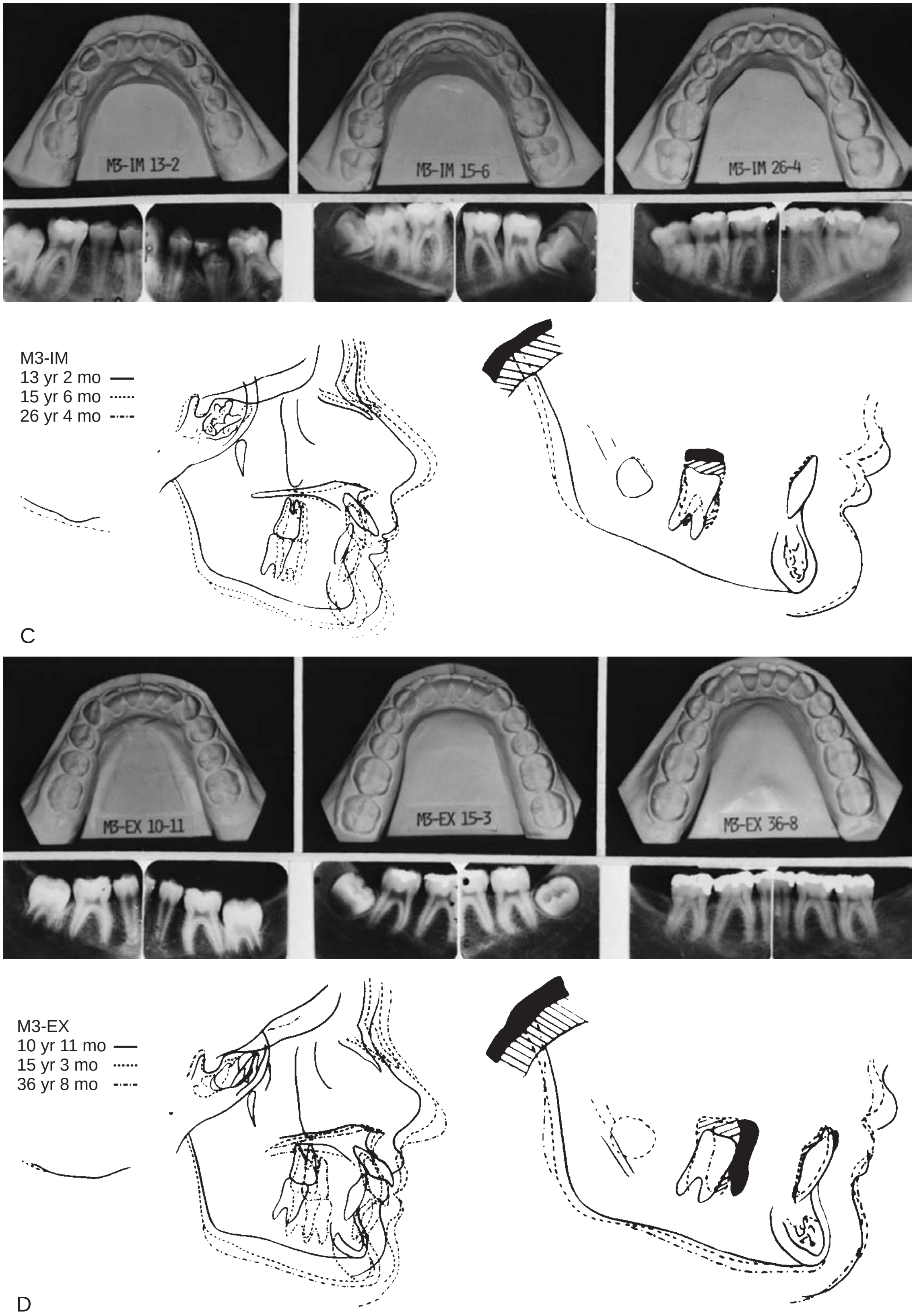


FIGURE 27-12, cont'd **C,** bilaterally impacted third molars (M3-1M); **D,** bilaterally extracted third molars (M3-EX).

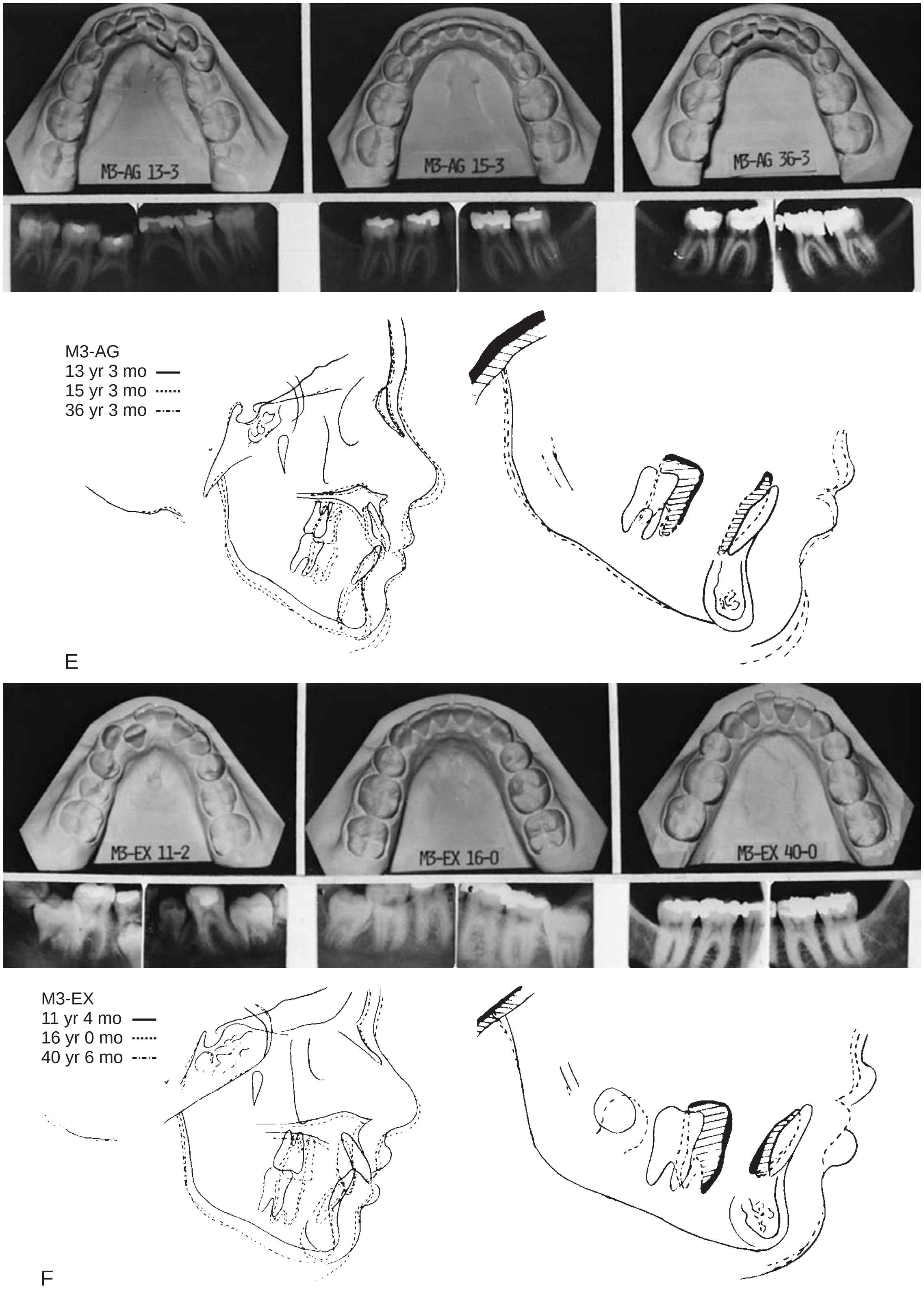


FIGURE 27-12, cont'd **E,** bilateral third molar agenesis (M3-AG) (note the amount of crowding); **F,** bilaterally extracted third molars (M3-EX). Treatment was completed at least 10 years before final records.

Growth Factors

Growth is an aid in the correction of many types of orthodontic problems, but it also may cause relapse in treated orthodontic patients. Orthodontists take advantage of growth when treating patients in the transitional dentition period with headgear anchorage[103] and removable or fixed functional appliances. For instance, cephalometric records suggest that cervical traction influences the normal downward and forward growth of the maxillary alveolar process, and possibly the growth of the maxilla itself may be inhibited or redirected.[74,104,105] The normal forward movement of the maxillary molars seems to be restrained, whereas the mandible continues in its course of growth, and a normal tooth relationship eventually may be reached.[106–108] Essentially, in the treatment of Class II cases, correction takes place primarily as a result of mandibular growth or forward translation of the mandibular teeth.[73]

To leave maxillary buccal segments tipped distally may be undesirable if this occurs secondary to headgear traction, particularly without any further mandibular growth. In most instances, these distally tipped teeth upright autonomously with the crowns moving in a mesial direction. If, however, sufficient mandibular forward growth occurs, the occlusion may continue to remain satisfactory.

Forward translation of the mandibular denture on its base after the use of Class II elastics or functional appliances is generally regarded as being undesirable, because most often the mandibular posterior teeth do not migrate distally again. Mandibular anterior teeth do attempt to upright to their former positions, frequently breaking contact and crowding as they move to the lingual. This type of treatment change is best maintained with a fixed retainer for mandibular anterior segment.

Gender Differences

In any discussion of growth, clinicians also must consider the gender of the patient when planning management in retention. Statistics derived by Baird,[109] Baum,[67,110] and Petraitis[111] from measurements in patients with excellent occlusions indicate a significant difference between the maturation of skeletal and dental patterns of males and females. An analysis of the skeletal and dental patterns of girls aged 11 to 13 establishes that they are not significantly different from those of women. Based on this and other investigations, one may conclude that on average the female skeletal and dental pattern matures by the thirteenth year.[112] In boys, the skeletal and dental patterns mature, on average, after the fifteenth year. This knowledge is significant in the treatment of skeletal Class II malocclusions, particularly in girls. Certainly the clinician must initiate treatment before the maturation of the skeletal pattern, independent of dental development, if growth is to be modified during therapy.

Further Implications of Growth

The implications of latent mandibular growth in the case of a true Class III malocclusion are so well known that few orthodontists attempt to complete orthodontic treatment or surgery until the child has ceased to grow. However, other growth peculiarities are of interest to the orthodontist. The amount and direction of mandibular growth may be of great importance in the correction and retention of corrected malocclusions.

Maturation changes can and do occur, particularly in boys, in relation to the apical bases and alveolar processes. In some, a so-called swing of the facial structures occurs out from beneath the cranium in late adolescence.[113] This swing may have the effect of reducing the angle of convexity, reducing the differences in apical base relationships, and increasing the compensatory angulation of maxillary and mandibular incisors to one another. A restriction of the mandibular denture may be produced in the process, resulting in uprighting of the mandibular incisors. The buccal segments may tend toward a Class III relationship. Usually the occlusal plane flattens, the mandibular plane decreases in relation to the Frankfort horizontal, and often the overbite is reduced. Several studies[71,114,115] have demonstrated that during growth, the permanent dentition has a natural tendency to become more recessive in relation to the body of the mandible and that, particularly in boys, the mandibular denture can be expected to erupt distally relative to the pogonion.

Continued posterior traction may be desirable on the maxillary arch in corrected Class II malocclusions, especially in patients whose mandibular growth is primarily downward or downward and backward. In boys particularly, continued retention in the maxillary and mandibular incisor areas may be desirable until growth changes have been completed. Many orthodontists make it routine practice to retain the mandibular anterior segment with a fixed retainer at least until skeletal growth is completed.

Functional appliances may play an important role during the retention period to assist in maintaining correction of skeletal components. These types of removable appliances can be worn during sleep to prevent changes in maxillomandibular position that may take place through continued unharmonious growth. These appliances are also effective in encouraging differential eruption and tooth movement in compensation for skeletal changes resulting from growth or relapse.

Recovery from Tooth Movements

With the possible exception of those who have an openbite malocclusion,[116] patients who have a Frankfort mandibular plane angle within the normal range generally can be expected to show a reduction in the angle with continued growth. If during orthodontic treatment the angle has increased, the angle may be expected to return to its former dimension or less if the patient continues to grow. If no further growth is expected, the return of the original mandibular plane angle will likely not occur. If, however, further growth is forthcoming and maxillary and mandibular teeth are retained in a position of minimal overbite, the subsequent increase in posterior facial height and leveling of the mandibular plane may occur without an increase in overbite.

Increases in the angulation of the occlusal plane to the sella–nasion plane or the Frankfort horizontal plane during orthodontic treatment are also undesirable because the general tendency is for these angles to decrease following therapy. Class II mechanics, for instance, will rotate the occlusal plane in a clockwise direction by extruding mandibular buccal segments, proclining and intruding lower incisors and extruding and tipping distally the maxillary incisors. If no further growth is forthcoming after the occlusal plane has been rotated in this manner, the subsequent recovery change of the occlusal plane angle may mean the return of an end-to-end or Class II relationship in the buccal segments or a deepened anterior overbite with return of overjet.[117]

Apical Base. Changes also may occur in the apical base relationships. For instance, what is recorded as an angle of convexity of 12 degrees in a boy of 8 years may someday be an angle of convexity of only 3 degrees, perhaps less. Hence, when attempting to relate incisors in inclination and bodily positions by means of a standard such as the ANB point angle or angle of convexity, the clinician must be aware of the implications of future growth changes in these relationships and of the tooth positions achievable by orthodontic treatment. One must recognize that the normal mandibular dental eruption pattern may be upward and backward away from the chin and that bony apposition may occur at pogonion itself. Thus, the relationship of the mandibular incisor teeth to pogonion at age 9 to 12 years is likely not a permanent position for these teeth.[103,118]

Speed of Treatment. Another consideration derived from growth studies is that rapid orthodontic treatment may not always be desirable. Instances may occur in which slower orthodontic treatment takes advantage of growth changes as in restraint of the maxillary growth and/or redirection of mandibular growth. For this reason, some patients may benefit from a two-phase approach with skeletal correction accomplished with more limited appliances and final occlusal detailing with comprehensive fixed appliances.

Duration of Retention. At this time, there is no consensus of how long to use retention appliances.[82] (See Chapter 14.) Does prolonged retention provide for greater stability? Will the use of retainers for 5 or 10 years provide for an adult dentition that shows less relapse than retention for 1 year or 6 months or not at all? Is prolonged mechanical restraint desirable? To date, no satisfactory comparison has been made of patients with similar malocclusions similarly treated but having significantly different retention protocols and durations. Most clinicians would consider "longer is better" but recognize significant individual differences in patients. Stabilization of tooth movement accomplished by way of orthodontics would seem to be accomplished for most patients within 12 months. Long-term maturational changes are often confused with "relapse" and, no matter what the label, may be attenuated with semipermanent retainer wear. The difficulty as a clinician is to determine exactly how long (hours/days/months/ years) to use retainers after treatment and with what frequency of wear. Indeed, it is often difficult to accurately assess actual time of wear of removable retainers by patients.

Musculature. Although a great deal is known about tooth position and arch form as they relate to the function of the oral and facial muscles, little of this information has been translated into useful clinical retention procedures.

Occlusal Adjustment. Treatment objectives should include the basic principles of gnathology such as canine disclusion and incisal guidance whenever possible. Stability can be improved with occlusal adjustment concomitant with or following orthodontic treatment that includes removal of interferences in centric relation and elimination of cross-tooth and cross-arch deflective interferences. Attempting to achieve perfect, final functional balance immediately after the completion of orthodontic treatment may not be desirable. The dental changes or "settling" that naturally occurs following appliance removal should be taken into consideration before undertaking extensive equilibration procedures. Indeed, any equilibration in the first 6 months after appliance removal should be solely for gross interferences.

Restorations can be recontoured, cusps and incisal edges adjusted, and teeth aesthetically recontoured where excessive function or lack of function has produced undesirable dental morphology. Periodic long-term observation of posttreatment changes and possible occlusal adjustment if needed are desirable and functionally useful.

CLINICAL APPLICATIONS OF RETENTION

Retention planning will divided into three categories, depending on the type and extent of retention treatment instituted: (1) limited retention, (2) moderate retention in terms of time and appliance wearing, and (3) permanent or semipermanent retention.

I. Limited retention required
    A. Corrected crossbites
        1. Anterior: when adequate overbite has been established
        2. Posterior: when axial inclinations of posterior teeth remain reasonable after corrective procedures have been completed. An exception is posterior crossbites treated with either

orthopedic or surgical expansion of the midpalatal suture. In these cases, overcorrection and long-term retention are desirable.

B. Dentitions that have been treated by serial extraction. The percentage of complete satisfaction secondary to extraction and autonomous eruption alone is typically rather low and depends on the degree of perfection desired by the patient and orthodontist. When extraction of the mandibular second premolars is possible or when they are congenitally absent, the resultant occlusions often are more satisfactory than those in first premolar serial extraction cases.[119]

C. High canine extraction cases

D. Cases calling for extraction of one or more teeth such as subdivision types of malocclusions, or when the posterior teeth are in Class II relationship and the anterior teeth are treated to a Class I canine position. Occasionally, lingual bonded retainers can be used to prevent extraction spaces from opening.

E. Corrections that have been achieved by retardation of maxillary growth after the patient is through growing.

F. Dentitions in which the maxillary and mandibular teeth have been separated to allow for eruption of teeth previously blocked out. Typical examples are partially impacted mandibular second premolars and maxillary canines.

II. Moderate retention required

A. Class I nonextraction cases, characterized by protrusion and spacing of maxillary incisors. These cases require retention until normal lip and tongue function has been achieved.

B. Class I or Class II extraction cases probably require that the teeth be held in contact, particularly in the maxillary arch, until lip and tongue function can achieve a satisfactory balance, as in the nonextraction group. Especially true in extraction cases is that the maxillary incisors can be retracted so far as to be unrestrained by lip pressure and to impinge on the space occupied by the tongue before treatment. Use of a maxillary removable retainer until normal functional adaptation has occurred generally is desirable. The time of application of this type of retention can be reduced as the patient adapts to new tooth positions, proceeding from full-time wearing of appliances to nighttime wear only, then perhaps every other night, once or twice a week, and finally wearing retainers at night as needed when they feel tight on insertion. Corrections of adult dentitions probably require longer retentive procedures. A predetermined time schedule for removing retentive appliances probably is undesirable in these cases, and the time of retention depends directly on the patient's compliance and reactions during retention. Tongue and myofunctional therapy may be advantageous in this group of corrected cases.

C. Corrected deep overbites in Class I or Class II malocclusions usually require retention in a vertical plane.[113,120,121]

1. If anterior teeth were depressed to achieve overbite correction, a bite plate on a maxillary retainer is desirable. To be effective in retaining overbite correction, the bite plate should be worn continuously for perhaps the first several months, including while the patient is eating. In deep overbite cases, overcorrection is usually desirable and occlusal adjustment to an ideal functional relationship is a consideration.
2. If overbite correction was achieved as a result of clockwise mandibular rotation, vertical dimension should be held at least until growth of mandibular ramal height catches up and neuromuscular balance can adapt.

A measure of bite opening can be assessed in the degree of change between the mandibular plane and a cranial base plane, such as the Frankfort or sella–nasion. Positive changes of the mandibular plane angle suggest continued retention until growth compensates or until the orthodontist determines that growth is complete.[13,51–54] This seems to suggest that correction of deep overbites is desirable before the completion of facial growth. The work of Matthews[98] in this field concludes that beneficial results may be achieved by beginning overbite correction as early as the primary or mixed dentition.

Severe occlusal plane tipping also may require extended retention protocols and possibly additional maxillary restraint as well. Examination of cephalometric films taken at about 6-month intervals will reveal whether adaptive growth changes have taken place.

D. Early correction of rotated teeth[46,50] to their normal positions

1. Perhaps before root formation has been completed
2. In the mandibular incisor area, a fixed lingual or removable type of appliance with a labial bow is probably best. In this area the occlusal splint-type or Hawley spring retainer may be useful (Figure 27-13). More recently, gingivectomy procedures have offered hope for increased stability of corrected rotations. Early correction of rotations, transeptal fiberotomy and long-term fixed retention may prove to be the most satisfactory.[13,51–54]

E. Cases involving ectopic eruption of teeth or the presence of supernumerary teeth require varying

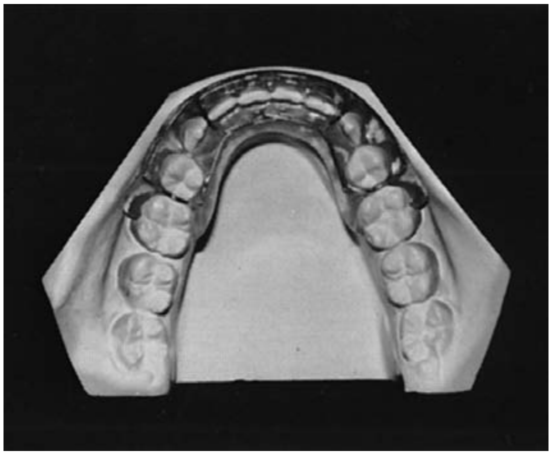


FIGURE 27-13 Mandibular splint retainer. Wire position can be altered to avoid passing through an extraction site or coming in contact with the maxillary dentition.

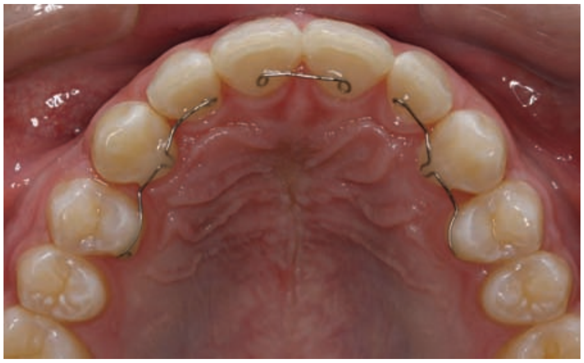


FIGURE 27-14 Lingual bonded retainers designed to prevent relapse of canines that were initially palatally impacted. A removable retainer is made to fit over and/or around the sectional wires to retain tooth position in other planes of space.

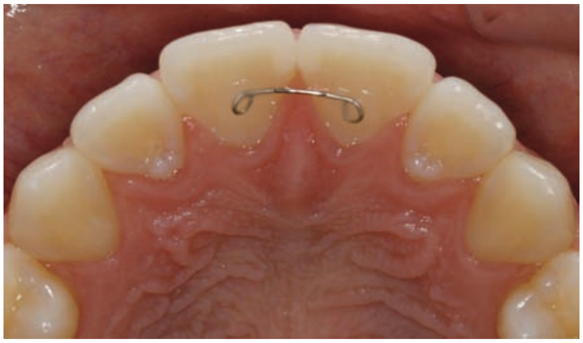


FIGURE 27-15 Lingual bonded 0.014-inch stainless steel wire to hold midline diastema from relapsing. Care should be taken to keep retainer out of occlusion with mandibular incisors.

retention times, usually prolonged, and occasionally a fixed or permanent retentive device, such as bonded lingual retainers.

1. Supernumerary teeth may be encountered in the maxillary anterior area and, on removal of these teeth, the maxillary incisors often erupt slowly and incompletely. When the latter have been brought to a normal level through orthodontic therapy, bonded lingual wires are desirable because these teeth seemingly have a tendency to reintrude when released. Palatally impacted canines, once brought into arch alignment, also may benefit from fixed lingual retention wires bonded to adjacent teeth to prevent reintrusion and palatal relapse (Figure 27-14).
2. Excessive spacing between maxillary incisors requires prolonged retention after space closure.

F. The corrected Class II, Division 2 malocclusion generally requires extended retention to allow for the adaptation of musculature. These cases, because they are typically treated without extractions, generally undergo some increase in mandibular intercanine width and present with malalignment of maxillary incisors, which needs to be maintained during retention.

III. Permanent or semipermanent retention required

A. Cases in which expansion has been the choice of treatment, particularly in the mandibular arch, may require permanent or semipermanent retention to maintain normal contact alignment. In many instances, patients have aesthetically desirable dentofacial relationships, and extraction of permanent teeth would create aesthetically undesirable results. The orthodontist may be faced with a choice between stability and aesthetics, and often the patient's aesthetic requirements take precedence.

B. Cases of considerable or generalized spacing may require permanent retention after space closure has been completed.

C. Instances of severe rotation, particularly in adults, or severe labiolingual malposition may require permanent retention, as provided by lingual bonded retainers.

D. Spacing between maxillary central incisors in otherwise normal occlusions sometimes requires permanent retention, particularly in adult dentitions (Figure 27-15).

RETENTION APPLIANCES

The Hawley retainer[24] is one of the most frequently used retentive devices available to the clinical orthodontist. The palatal or lingual portion usually is constructed of acrylic and may cover the palatal mucosa completely or can be constructed in a horseshoe shape contacting the lingual surfaces of the teeth and a limited amount of palatal mucosa. A labial bow of round stainless steel 0.020- to 0.036-inch wire usually is constructed to

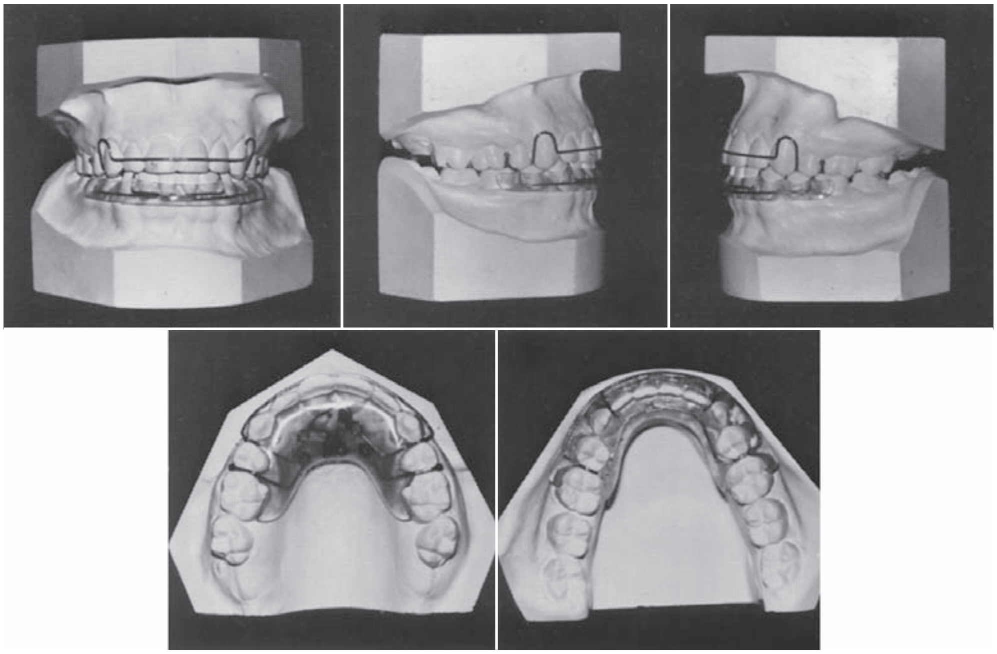


FIGURE 27-16 Typical Hawley and splint retainers. Note that the models should be articulated in occlusion to ensure that the patient is not contacting prematurely on retainer wires or acrylic unless an anterior bite plate is desired.

contact the labial surfaces of four or six maxillary anterior teeth (Figure 27-16). Constructing the wire to cross incisally through the contact area between the canine and the lateral incisor may minimize occlusal interference in the area of the mandibular canine. If such construction is used, inclusion of a restraint on the labial of the canines to prevent their extrusion or labial drift is desirable.

The clinician may wish to alter the type and position of retention clasps to avoid traumatic occlusal interferences and to assist in eruption guidance or minor tooth movements, such as erupting second molars (Figure 27-17). Additionally, the labial bow and retention clasps should not pass through extraction sites if possible because they may aggravate the tendency for space to reopen, especially in adult patients.

Circumferential maxillary retainers provide excellent retention with the added benefit of eliminating potential occlusal interferences and holding space closed (Figure 27-18). The clinician may place "keeper" wires between the lateral incisors and canines or flow acrylic on the wire facial to the maxillary anterior teeth to enhance the stability of the labial wire. The clinician also can adjust labial bow tension efficiently if recurved loops are included. Palatal acrylic should be extended distally to retain second molar position. This is particularly important in patients who have undergone changes in transverse dimension during active treatment, such as surgical or sutural maxillary expansion.

Pontics may be included in the retainer design to enhance aesthetics and retain the edentulous area(s) during the transition from fixed appliances to prosthetic replacement of missing teeth (Figure 27-19). Lingual bonded segmental wires are used to prevent the teeth from drifting into the edentulous areas, and a "flipper" with pontic(s) made to fit over the bonded wires is worn during the day for aesthetics (Figure 27-20). After placement of implants, the retainer can be relieved in the gingival area to allow maintenance of dental aesthetics while avoiding tissue impingement during the osseointegration stage. The clinician may adjust the retainer after completion of the prosthetic phase simply by removing the pontic and recontouring the palatal acrylic to fit the final restoration.

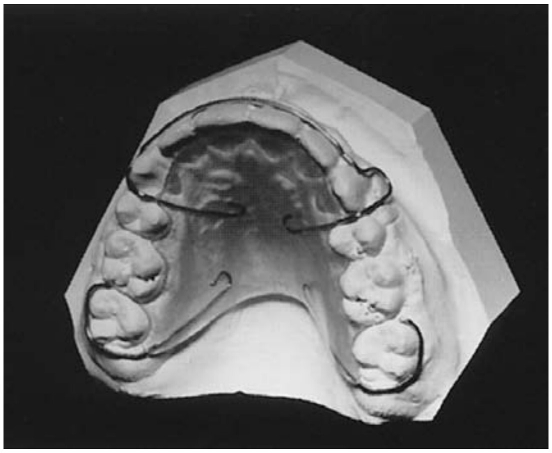


FIGURE 27-17 Maxillary Hawley retainer with C clasps to guide second molar eruption.

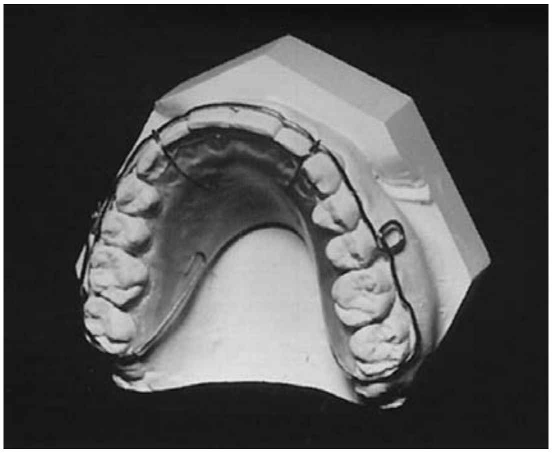


FIGURE 27-18 Maxillary circumferential retainer. Palatal acrylic can be reduced to minimize effects on speech and swallowing patterns. Note recurved loops to allow adjustment of tension.

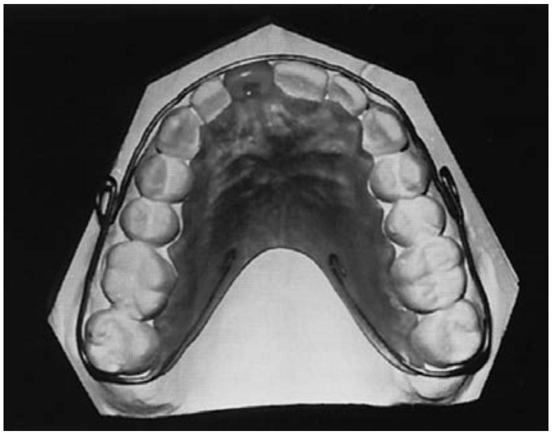


FIGURE 27-19 Maxillary circumferential retainer with pontic to replace missing right central incisor.

A clear removable retainer with pontic(s) held in place within the plastic is also typically made to be worn at night or for use in emergency situations if the regular retainer is lost or broken. The clear retainer is stronger and acts as a nightguard to prevent breakage of the pontic from grinding or clenching during sleep (Figure 27-21).

The clinician also may alter the size of a retainer to accommodate special needs. A mandibular spring retainer, for instance, may include only the six anterior teeth to eliminate the difficulty of seating such an appliance over buccal segment undercuts, which are fairly common in adult patients with long clinical crown heights, or undercuts created by lingual crown torque (Figure 27-22).

The clinician may also use fixed retention appliances to retain potential areas of relapse more securely and to reduce the dependency on patient compliance (Figure 27-23). The development of bonding materials has facilitated the fabrication of segmental retainers that splint together two or more teeth to maintain intraarch tooth position. The wires used for such retainers should be

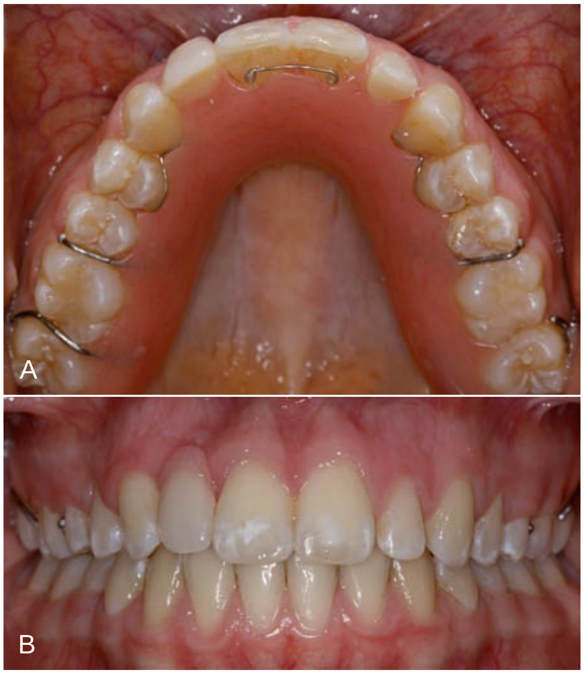


FIGURE 27-20 **A,** Maxillary flipper with pontic to replace right lateral incisor. The flipper is made to fit over and/or around sectional wires bonded on the lingual to prevent teeth from drifting into edentulous areas. **B,** Flipper in place for aesthetic replacement of maxillary right lateral incisor. Note the use of pink acrylic gingivally to blend into oral mucosa.

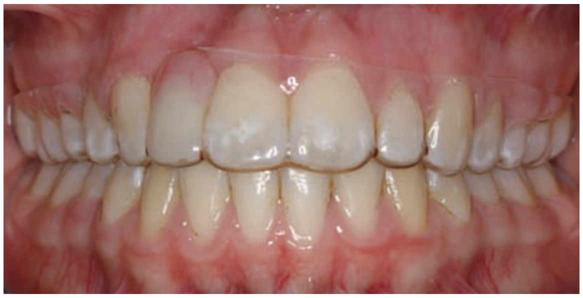


FIGURE 27-21 Clear retainer with the maxillary right lateral incisor pontic used during appliance therapy transferred and included in the retainer.

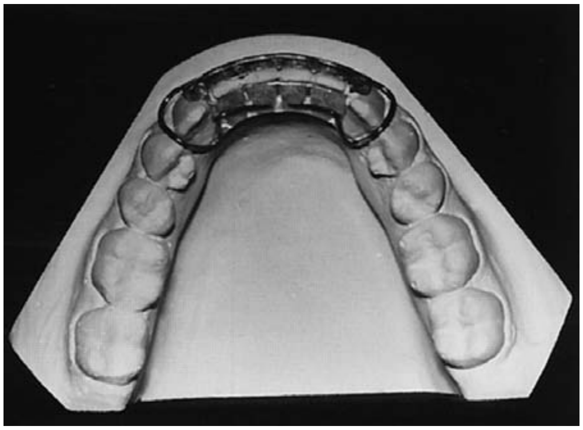


FIGURE 27-22 Mandibular spring retainer modified to maintain only anterior tooth position.

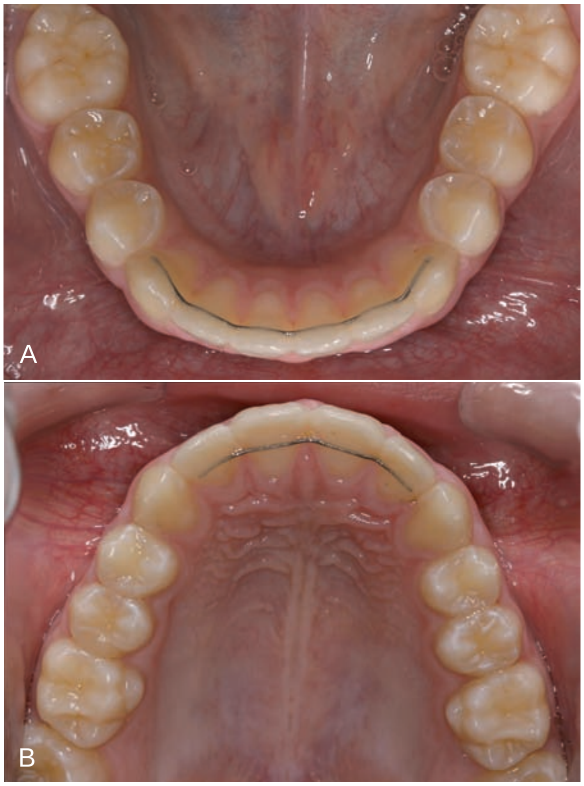


FIGURE 27-23 **A,** Mandibular bonded retainer. A braided wire is bonded to each tooth but allows physiologic tooth movement. **B,** A maxillary bonded retainer may also be placed to prevent relapse of initial spacing or irregularity. This retainer must be positioned and contoured to prevent premature mandibular incisor or canine contact.

flexible enough (0.0175 twisted or 0.014 to 0.016 stainless) to allow physiologic tooth movement. One also may use bonded retainers effectively to hold extraction spaces closed if relapse is anticipated (Figure 27-24). Canine-to-canine bonded retainers can also be extended distally to include premolars if the premolars were initially ectopic or if it is the intent to hold extraction spaces closed, as in adult extraction cases (Figure 27-25). The clinician can also fabricate removable retainers to fit over bonded retainers to minimize potential relapse in the other planes of space and to maintain interarch relationships.

Studies[122,123] conclude that fixed bonded retainers are as healthy dentally and periodontally as wearing removable retainers if they are maintained with proper oral hygiene techniques. The clinician can consider, however, eventually removing fixed retention and fabricating removable retainers to be used as needed to minimize the impact of long-term relapse and maturation changes.

THE POSITIONER IN RETENTION PLANNING

The positioner appears to be particularly beneficial in reestablishing normal tissue tone and firmness where gingival hyperplasia has occurred during treatment. The advantages of a positioner are that it is clean and unlikely to be broken, tends to stimulate tissue tone, and works constantly toward maintenance or improvement of tooth position. The disadvantages are its limited time of wear because the patient can neither eat nor talk with the positioner in place and the possibility that it may keep teeth loose by producing intermittent forces contrary to natural muscle balance. The positioner probably is contraindicated in patients who have a tendency for nasal airway obstruction and are mouth breathers due to the difficulty of breathing with a positioner in place.

If a positioner is to be used on what has been a deep overbite malocclusion, construction of a maxillary retainer with a bite plane to be used when the patient is unable to wear the positioner is a beneficial adjunct. Construction and placement of a positioner that fits over a fixed appliance such as a lingual bonded retainer are also common.

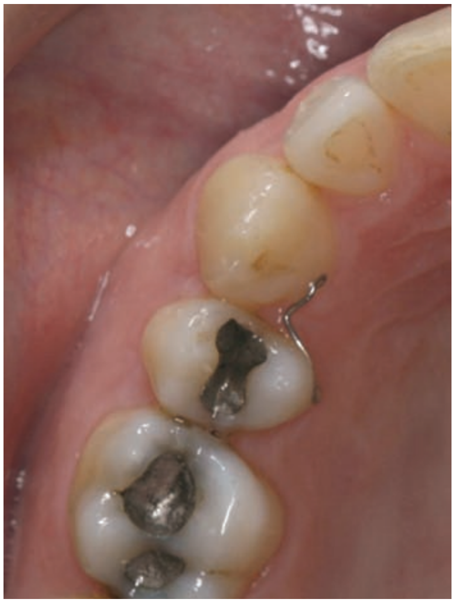


FIGURE 27-24 Sectional wire bonded on the lingual to hold an extraction site closed.

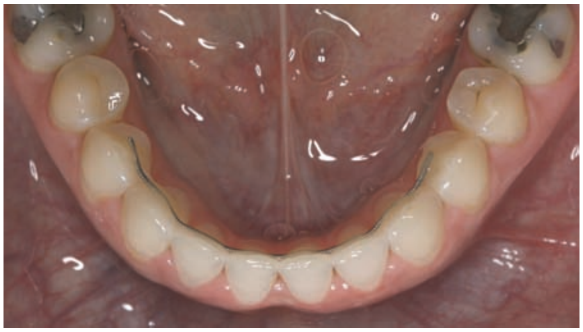


FIGURE 27-25 Mandibular bonded retainers can be designed to extend distally to include premolars if premolars were initially ectopic or to hold extraction sites closed.

Positioner setups and fabrication should be done on an adjustable articulator after a facebow transfer (Figure 27-26) to allow the patient to function into the positioner without altering condyle–fossa relationships.

DURATION OF RETENTION

As noted from the literature, various authors suggest anything from no retention whatsoever[47] to permanent retention.[84] Some form of mandibular retention probably will be maintained until evidence of completion of growth is forthcoming, and one should consider use of retainers as needed and indefinitely to ensure maintenance of tooth relationships. The clinician should discuss retention procedures with patients before starting orthodontic treatment to impress upon them the importance of the retentive phase that follows active treatment. Retention may be described as a 12-month "healing phase" during which the newly made movements of teeth are stabilized and a "maintenance phase" to guard against the maturational changes in tooth position that occur over time. The latter purpose is, of course, long term.

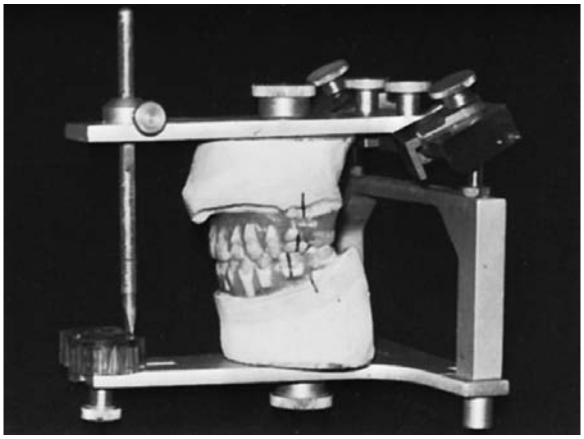


FIGURE 27-26 Diagnostic setup completed on an adjustable articulator after a facebow transfer. Fabrication of the positioner on this type of instrument allows the patient to bite into the positioner without altering condylar position.

RECOVERY AFTER RELAPSE

If, despite the utmost care in treatment and retention, relapse or further postorthodontic maturational change occurs, the following suggestions may be useful:

1. Retreatment may take the form of rebanding or rebonding some or all teeth. Admittedly, this is an extreme measure, but it may be necessary to accomplish the desired correction. Permanent and long term retention is likely preferable following retreatment. In any case, one should attempt to discover and eliminate factors that appear contributory to the relapse.
2. The mandibular lingual arch serves admirably to realign teeth in instances of mandibular collapse or crowding. Light pressure against the mandibular anterior teeth may be used to realign them.
3. Springs and clasps can be added to removable retainers to assist in repositioning and controlling labiolingual deviations.
4. Spring retainers using facial and lingual acrylic for added leverage or clear aligners may be used for minor realignment. Teeth are sectioned and aligned as in a diagnostic setup and the active retainer is fabricated to the realigned relationship (Figure 27-27). The same "spring" retainer(s) used for alignment can be used to maintain the correction achieved. Interproximal stripping is sometimes beneficial as determined by the setup.
5. A headgear or functional appliances may be used against the maxillary arch during growth to provide recorrection in instances of relapse toward a Class II relationship.
6. Habit training in the form of tongue and lip therapy may be beneficial when abnormal habit patterns have contributed to orthodontic relapse. Removable

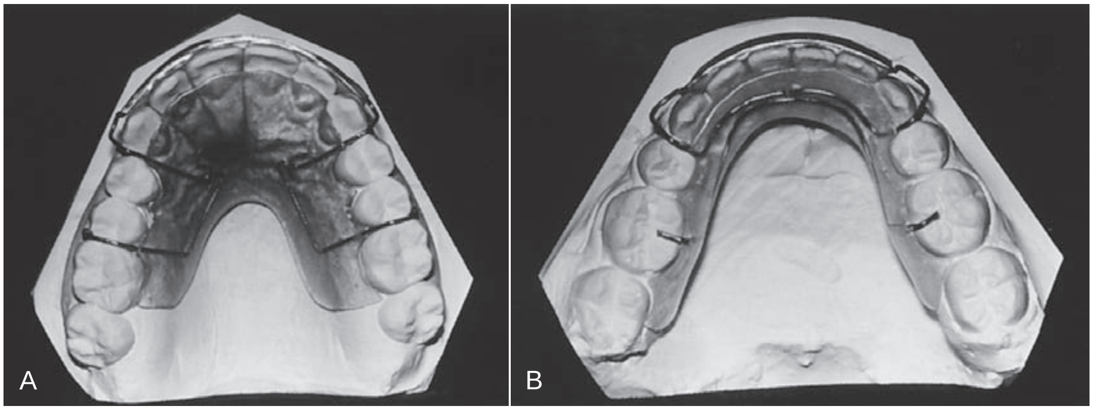


FIGURE 27-27 Maxillary and mandibular spring retainers. Incisors have been realigned in the working model.

appliances are also helpful as tongue restraints and trainers.

7. Occlusal adjustment and interproximal tooth size reduction may be desirable to achieve an optimal aesthetic and functional result. Interproximal “stripping” or reduction in crown width may reduce the tendency for further relapse.
8. In certain cases, the clinician may suggest that the patient accept minimal relapse rather than continue with prolonged retreatment and retention.

SUMMARY

Retention is not a separate problem but is and will continue to be a problem to be considered during the initial and ongoing diagnosis and treatment planning for patients. As Oppenheim[58] so aptly stated, “Retention is one of the most difficult problems in orthodontia; in fact, it is the problem.”

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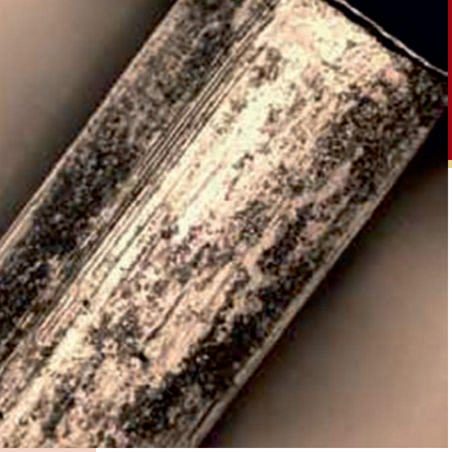

CHAPTER 28

Dental Materials in Orthodontics

Theodore Eliades

OUTLINE

Impact of Appliance Properties on Mechanics
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    Roughness
    Base-Wing Joint
    Hardness
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Summary

The application of dental materials science in orthodontics coincided with the use of gold and steel wire alloys by E. Angle, although the father of the specialty might not have imagined the impact that materials and technological advancements would have in current orthodontic practice.

As the field progressed and grew to receive the dimensions of a specialty, the incorporation of principles of mechanics and materials, which are typically taught in the first year of an undergraduate engineering curriculum, were introduced in the postgraduate orthodontic curriculum. Elements of this discipline appear already from the first edition of R. Thurow's *Technique and Treatment with the Edgewise Appliance* in 1962 and were more formally introduced in the second edition in 1966. Clinically oriented biomechanical principles integrating mechanics of materials were also included in chapters of the first edition of Graber's *Current Principles and Techniques* in 1969.

In the United States, the emphasis on mechanics received extraordinary attention, possibly because of the unique educational system and the requirement for a previously earned degree prior to applying to dental school. This prerequisite allowed for the cultivation and growth of the materials research because dental graduates entering orthodontic programs were equipped with a bachelor's level of formal training in natural or engineering sciences, thus bringing a new perspective to traditional and empirically taught concepts of mechanics.

Although the number of prominent figures who shaped this field is long, there are certain names that would probably be included in every list, most of whom contributed to mechanics, material, and clinically applied mechanotherapeutic principles—R. Nikolai, who contributed a prototype of engineering analysis of orthodontic mechanics; C. Burstone, without whom the specialty would have been deprived from key principles of biomechanics, the variable modulus orthodontics, and new wire alloys; R. Kusy, for the prolific work on wires and uncovering the world of friction; F. Miura, for the introduction of Japanese nickel-titanium (NiTi) alloys to the profession; W.A. Brantley, for contributing to the understanding of phase transformations of these wires; and B. Melsen, who, along with C. Burstone, was the first to realize the need for an enhanced biomechanics training and develop an innovative, at the time, biomechanics curriculum in standard postgraduate orthodontic education.

The chapter on orthodontic materials by C. Matasa on the previous edition of this textbook provided an

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overview of topics that had never been previously included in a textbook.[1] It was decided for this edition that the focus should be on analysis of the impact of various material properties on mechanics and treatment. Thus, the emphasis of this chapter will be on the actual differences that material properties may have on mechanotherapy rather than typically reporting various properties of metallic and polymeric materials. This practice-centered approach will attempt to explain clinically encountered phenomena based on materials science principles. Moreover, a new section will briefly summarize the potentially hazardous action of several factors associated with orthodontic treatment.

IMPACT OF APPLIANCE PROPERTIES ON MECHANICS

Stainless Steel Brackets

Terms such as *modulus of elasticity, hardness,* and *roughness* have been added to the glossary of orthodontist in everyday practice, probably due to the recent literature on the subject. Although the actual meaning of these terms has been defined early in dental studies, the orthodontist may not be cognizant of the actual frequency of their use during routine practice. The following paragraphs will examine these parameters for brackets and analyze their importance in defining the performance of metallic, polymeric, and ceramic appliances (Table 28-1). For a more formal treatise of the subject the reader is referred to Brantley and Eliades' orthodontic materials textbook, where the atomic arrangement, bonding, and mechanical properties are analyzed.[2]

TABLE 28-1 The Role of Mechanical Properties in Treatment

Property	Effect on Mechanotherapy/ Performance
Modulus of elasticity (*E*)	Low *E* allows for deformation at low forces facilitating ease in debonding (peel-off effect) because of plastic deformation of base High *E* provides resistance to deformation during engagement of archwires (especially torque) of wings and slot
Hardness	Structural integrity against the applied loads during engagement of wire into the brackets slot
Roughness	Full seating of wire into the slot, shielding against high forces arising from the decreased contact points between wire and slot surfaces

Adapted from Eliades T, Pandis N, editors: *Self-ligation in orthodontics,* London, 2009, Wiley-Blackwell.

Stiffness. Stiffness reveals the resistance of the appliance to deformation (within the elastic range). This property has various implications for the understanding of several phenomena encountered during practice. High stiffness (or high modulus of elasticity) implies high resistance to deformation and as such is suitable for the areas where no deflection is preferred. These include the slot walls and wings, which should not be compliant to allow for efficient transmission of the loads applied by an activated archwire to the tooth. The reader would appreciate the importance of stiffness by considering the train-railway analogue: railway alloys receive a special surface treatment to gain high stiffness so that they are not deformed during the course of movement, and no obstacles are presented to impede rolling of the wheels. To this end, ceramic brackets show higher stiffness as a result of the arrangement of atoms and bonding inside their structure, and for this reason they present better performance when it comes to transmission of loads, whereas plastic brackets, apart from their lower stiffness, which in most cases make them unsuitable for this task, show several other disadvantages.[2] For example, cyclic hardening or softening in metals depends on the composition, previous cold work, and temperature in metals, whereas polymeric materials exhibit a cyclic softening effect. Also, loading rate and ambient temperature changes alter substantially the stress-strain characteristics of polymers.[2] In addition, when cyclic loading involves increased strain rates, a thermal softening effect may be induced, leading to a reduction in the fatigue life.[5]

Whereas high stiffness is preferred for some components of the brackets, for others, such as the base, this is an undesirable feature. This is due to the difficulty in squeezing a stiff base at debonding, which necessitates the application of increased forces; this effect coupled with the sensitive and sore teeth increases the discomfort and pain during this stage. For bases, a compliant or low stiffness alloy is preferred because this bracket component is not an active part of treatment. Box 28-1 summarizes the role of stiffness on desired bracket characteristics, whereas Figure 28-1 depicts the variable hardness of bracket components.[6]

Roughness. Roughness may differentiate the force because of the effective contact between the wire and bracket. At the microscopic level, this contact is not continuous but possesses a profile of opposing peaks arising from the variation of surfaces between the two materials coming in contact. For a given force application, and nominally identical roughness, force would be much higher in the pair of slot-wire, which shows the least number of high peaks. Increasing the number of peaks in contact while maintaining steady force results in an increase in the surface area and an overall decrease

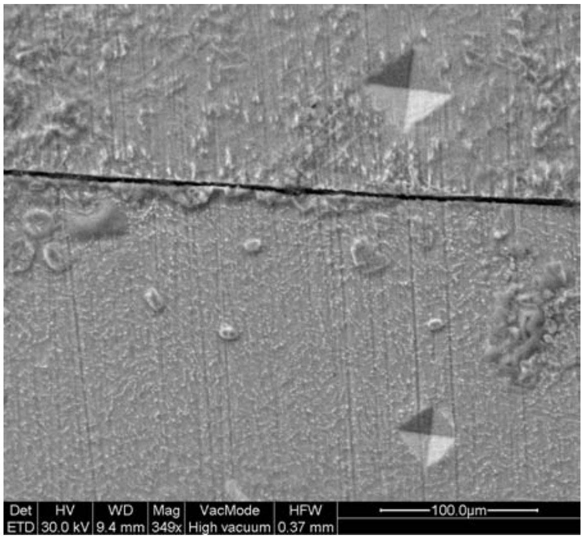

FIGURE 28-1 Secondary electron image of a Ti bracket demonstrating the difference in hardness between the wings (small pyramid indent) and base (large pyramid indent) (original magnification ×349). The difference in the size of pyramids corresponds to the different alloys used for bracket manufacturing.

BOX 28-1 The Role of Stiffness in Different Bracket Components

Various bracket components require different stiffness variants. Wings and slot should be of high stiffness, whereas the base should be compliant for different reasons: wings must withstand the loads applied without being deformed, whereas the base must furnish easy peel-off effect.

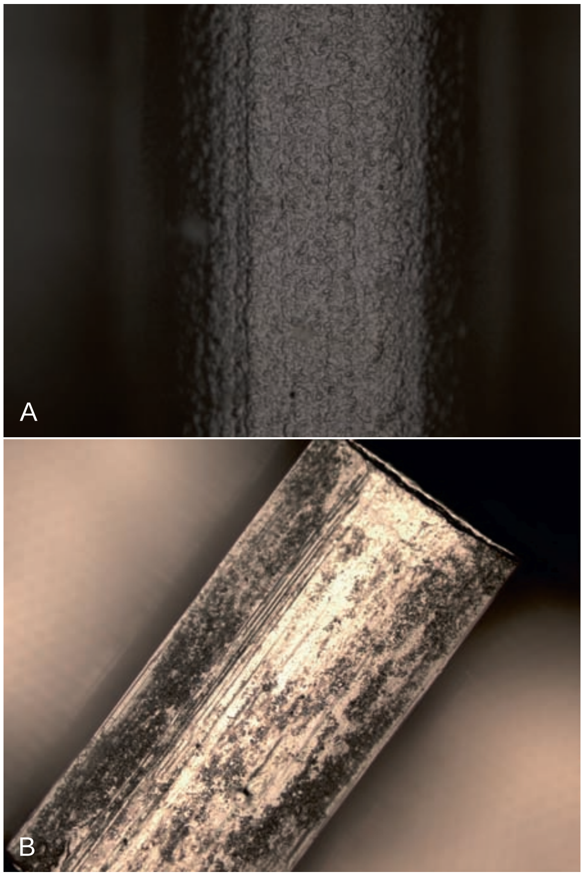

FIGURE 28-2 Optical dark field images of the slot surface of a ceramic **(A)** and stainless steel bracket **(B)** demonstrating the increased roughness of the surfaces. (original magnification ×10)

in the resultant pressure applied to the bracket. Figure 28-2 illustrates the roughness of slot surfaces.

The implication of roughness in friction during sliding mechanics has been overestimated, and several research and review articles have demonstrated that the rougher wires did not consistently show the highest friction.[7]

Base-Wing Joint. The puzzle of combining both features (a stiff wing and compliant base) was solved with the application of welding or soldering of two different alloys.[8,9] Alloy soldering is used to join the two bracket components. Initially, stainless steel brackets were brazed with silver (Ag)-based filler alloys, which are also the most frequently used brazing filler metals for stainless steel in industrial applications. However, orthodontic silver brazing alloys contain the cytotoxic element cadmium (Cd), which is added to lower the melting temperature and improve wetting.[10,11] Moreover, Ag-based brazing alloys introduce a galvanic couple with stainless steel alloys, inducing release of metallic ions with copper (Cu) and tin (Zn), the most easily leached out elements from Ag brazing alloys. Because brazing alloys that contain Cu and Zn are cytotoxic, galvanic corrosion, which is the main reason for the progressive dissolution of brazing filler metal,[12] may have both mechanical (detachment of the base-wing component) and biologic implications.[13–17]

To overcome this problem, several manufacturers have introduced gold-based brazing materials. However, this may lead to dissolution of stainless steel, which is less noble than the gold alloys, and this may be the explanations for the in vivo corrosion of bracket bases as well as for Ni leaching from stainless steel alloys.[18] Metal ion release[19] from brackets and orthodontics appliances in general is of great concern regarding the adverse effects of allergic reactions or cytotoxic effects.[20]

The use of new alloys for the production of metal injection molding (MIM) brackets may affect their mechanical performance under clinical conditions. Brackets produced by MIM technology are actually single-piece appliances and thus supposedly free from the corrosion risk associated with the galvanic couple of brazing alloys with stainless steel. However, appliances manufactured with the MIM method, have shown extended porosity.[8]

Last, laser-welding has not been expanded and a limited number of products are fabricated with this method. The main advantages of the method relate to the fact that whereas the concept of two alloys with different stiffness can be used, the absence of intermediate phase and potential corrosion risk optimizes the prospective performance of the final product. Box 28-2 summarizes the characteristics of base-wing joint.

Hardness. An increased hardness, as in the case with stiffness, is necessary to facilitate surface integrity and preclude binding of the wire onto the bracket slot walls. The latter may affect the force levels experienced by the tooth by increasing the friction variants, necessitating thus an increase in force to achieve tooth movement.[2,19] This is based on the significance of surface roughness on slot–archwire interfacial sliding during displacement of bracket along the archwire. Reduced hardness of the slot results in impingement of the wire into the bracket slot walls, leading to an impeded movement.

The Vickers hardness number (VHN) of MIM-manufactured brackets has been found to vary between 154 and 287, which found much lower than the hardness (400 VHN) of wing components of conventional stainless steel. This difference may have significant effects on the wear phenomena encountered during the archwire activation into the bracket slot.[21] Stainless steel archwires demonstrate a hardness of 600 VHN while the hardness of NiTi archwires ranges from 300 to 430 VHN. As a rule, a mismatch in hardness is not desirable because it promotes wear across the path of an archwire into a slot. The clinical significance of the hardness finding may pertain to the fact that low-hardness wing components may complicate the transfer of torque from an activated archwire to the bracket and may preclude full engagement of the wire to the slot wall and possible plastic deformation of the wing.[21–23]

Friction. Bracket–archwire friction has received a wide attention during the past 15 years. A search in the PubMed database with the keywords “friction” and “orthodontics” reveals about 300 articles, with the vast majority including laboratory configurations involving sliding of a wire onto bracket slots. A number of critical reviews have demonstrated the clinical irrelevance of the typical in vitro assessment of friction protocols presented in a large number of studies during the past decade.[24–29]

Various factors related to the oversimplification of experimental configurations and an overwhelming number of assumptions in the experimental design have deprived ex vivo friction assessment from the clinical relevance and scientific soundness required to establish this issue as clinically vital. These briefly include the inappropriateness of the use of the terms “friction” and “sliding resistance” interchangeably, the clinically irrelevant choice of rate of wire sliding onto slot walls, lack of intraoral aging of materials, and study of variables, which possess little or no relevance with the actual clinical analogue.[29] A thorough analysis of the incoherence of the majority of friction research protocols is provided in the Brantley and Eliades orthodontic text.[3] In addition, the poor clinical significance of this research has been illustrated with the listing of a number of technical, clinical, and methodologic factors, which differentiate the impact of friction derived from laboratory experiments relative to the one encountered in clinical conditions. These mainly include the presence of vibrations on the wire inside the slot arising from masticatory forces and the inappropriateness of using the term “friction” when studying resistance to sliding.[29] The former differentiates the direction of movement and leads to a pattern resembling incremental tipping; this in turn eliminates the importance of resistance to horizontal sliding of a wire into the slots as used in laboratory friction experiments. Box 28-3 summarizes the factors that render conventional friction protocols methodologically incoherent and clinically irrelevant.

During the past 5 years, the results of a body of evidence on this issue derived from clinical trials suggest that the bracket–archwire free play may not be the most critical factor in altering tooth movement rate.[30–33] In general, the majority of clinical trials are not supportive of a faster tooth movement rate in “low-friction” brackets.[30–33]

The large clearance and presumed lower binding of low friction bracket–wire combination relative to a conventional one may be eliminated as archwires of larger cross sections are gradually inserted in the bracket slot. The clinician may empirically appreciate the free play with low-friction brackets, especially in cases of extreme tooth malalignment, where full engagement of a large-diameter NiTi wire to conventional brackets requires

BOX 28-2 Bracket-Wing Joints in Metallic Brackets

Base-wing joint is achieved with alloy (Ag, Ni, Au) soldering with potential problems with galvanic corrosion or ionic release, or laser welding with lack of soldering medium and absence of unfavorable effects. MIM brackets are one-piece appliances and show lack of galvanic corrosion, but have higher porosity and are made of one alloy type, which does satisfy the requirements for a stiffer wing component and compliant base.

BOX 28-3 The Overestimation of Actual Clinical Impact of Friction

In vitro assessment of friction includes many assumptions and oversimplications such as horizontal pathway of wire into the slot; arbitrary movement rate; absence of aging of materials; lack of vibrational movements arising from mastication, which cancel out the frictional resistance; and measurement of an irrelevant component (force required to introduce sliding). Recent clinical trials testing brackets or wires with different fiction do not show difference in treatment duration.

increased pressure. In this first stage, there is a definitive advantage of low-friction brackets relative to conventional appliances; this situation, however, changes drastically as treatment progresses and wires of higher stiffness are engaged in the bracket. Completion of the correction of rotations and achievement of proper buccolingual crown inclination (torque), which are frequently required in the mandibular and maxillary incisors, respectively, necessitate the presence of a couple of forces. This assumes the formation of contacts of wire inside the bracket slot walls to generate force, and thus the major advantage of low-friction brackets, namely, the free play, is eliminated as tooth crowns gradually obtain their proper spatial orientation.[34]

Apart from the foregoing factors, in vitro studies dealing with this issue have shown that friction increases with increased roughness of the wire or bracket surfaces, although the opposite has also been suggested. Studies have indicated that beta-titanium and NiTi wires and ceramic brackets have shown increased friction due to their roughened surfaces arising from the manufacturing process. Nonetheless, Kusy and Whitley[28] have shown that although β-Ti (Titanium Molybdenum Alloy or TMA) wires exhibited the highest coefficient of friction, the highest roughness was obtained from NiTi wires, with evidence of mass transfer from the beta-titanium wire to the stainless steel and polycrystalline alumina contact flats, attributed to the relatively low compressive yield strength of the beta-titanium wire alloy.

Moreover, frictional testing in most cases involves dry and relatively clean samples (i.e., wires and brackets), and therefore no biofilm or calcified regions are included.[35] The adsorption of these intraoral integuments might increase the surface roughness and resistance to shear forces. A prominent fluctuation of the curve of the frictional loss over the measured displacement of the bracket along the wire has been noted; this could be attributed to the complexes precipitated intraorally.

Material Properties and Torque. Proper buccolingual crown inclination is a key factor to achieving appropriate interincisal inclination and adjusting for minor discrepancy in arch length,[36] and may concomitantly be critical in avoiding relapse of deep bite correction, especially in a typical Angle Class II, Division 2, case. Whereas torquing auxiliaries constitute an efficient means of achieving torque, with the advent of the straight wire technique, the ideal buccolingual inclination was identified in teeth of aesthetically pleasing smiles with Class I occlusions; this value was then incorporated into the bracket slot prescription. However, such a transfer assumes ideal materials, no torque loss due to slot design, accuracy of prescription with minimum deviation from actual and reported prescription values, and full expression of the prescribed value. Unfortunately, none of the foregoing assumptions is valid and the reason is that we deal with real materials, which possess various defects.[23]

Let us examine the sequence of events associated with the engagement of a rectangular wire into a bracket slot. First, the edges of the wire will have to be twisted to come in contact with the slot walls, to an extent determined by the size of the slot and the cross section of the wire. The rotation of the wire into the slot prior to contact with the bracket is expressed as *torque loss,* alternatively termed *free play, clearance*, or "slack." The value of this loss has been found to show a difference between theoretical estimation and experimentally derived values, with higher loss occurring in measurements. The source of this discrepancy may be attributed to the rounded edges of the bracket and slot, as well as the tolerance in size; that is, the slot is slightly larger than described and the wire smaller than defined by the manufacturer. The magnitude of this slack is in the order of 10 degrees for a 0.016- × 0.022-inch archwire engaged into an 0.018-inch slot,[37] thereby eliminating the torque transferred to the a maxillary central incisor with a Roth prescription appliance, leading to undertorqued anteriors. If this is a Class II case with protruding incisors, then the outcome will not be unfavorable; however, in an occlusion with uprighted incisors, the result will not be acceptable.

As the wire is brought in contact with the slot walls, there is a tendency for the former to be pushed out of the slot because the stresses developed tend to displace it labially. Thus, a second factor—namely the efficiency of ligating medium—comes into play. Elastomeric ligatures are a poor means to secure the wire in place because of the relaxation they present, which reaches high values within the first 24 hours.[38] For this reason, stainless steel ligatures are suggested to increase friction, which in this case is desirable, because otherwise there will be no adequate inclination change.

Having eliminated the foregoing variables on slack, the next step is the application of stress of wire onto the slot wall surfaces. As the wire applies a force to the bracket, the wire or the bracket will experience a surface alteration, which will be determined by the difference in hardness. The harder material will leave an imprint in the softer material, and in most cases that is the stainless steel on NiTi and TMA wires and stainless steel wire in Ti or plastic brackets. Also, TMA wires will leave traces of material in ceramic brackets. The resultant wear will presumably take out some of the activation of the wire, further decreasing the potential for torquing the crown of the tooth.

When finally, the residual activation outweighs all the above-mentioned obstacles, the torsional stiffness of the materials may modulate the torque expression.[39,40] R. Kusy[41] very effectively described this relationship with the construction of nomograms, where the relative stiffness in torsion of various sizes of archwires is provided in a scale. Figure 28-3 depicts the relative torsional stiffness of various alloys of different cross sections.

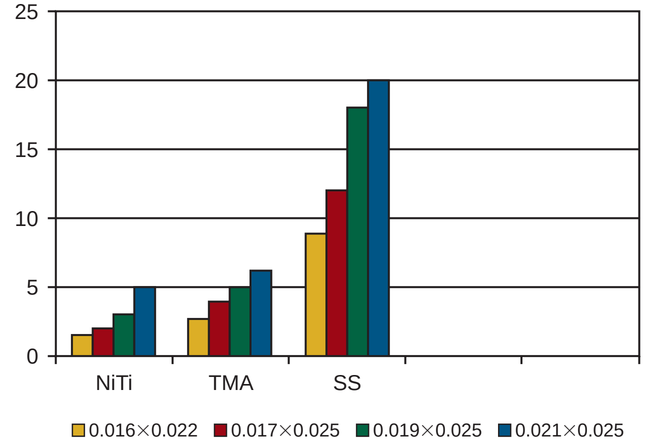

FIGURE 28-3 Graph depicting the relative torsional stiffness of wires of various cross sections and compositions demonstrating that the increasing the size of the wire does not secure more effectiveness in torquing crowns. *(Compiled from data presented by Kusy, 1983.)*

BOX 28-4 Factors Affecting Efficient Torque Expression with the Straightwire® Technique

Torquing with the Straightwire technique requires large cross section stainless steel wires or NiTi wires with a pre-torque of almost 40^0 of activation; stiff wings and wires; hard wing and wire surfaces and an inelastic ligating medium, with minimum relaxation with time.

Thus, although a 0.017- × 0.025-inch NiTi archwire in a 0.018-inch slot will result in a decreased play compared with a 0.016- × 0.022-inch archwire in the same slot, its torsional stiffness is much lower than the latter. This reveals that a larger cross section is not the critical factor in determining torque efficiency. The emphasis placed on the size of wire as an indication of its stiffness derives from the fallacy of notion that a larger wire will always express the slot prescription more efficiently than one of a smaller cross section. This concept has its roots in the time when orthodontists were able to increase the stiffness of the wire only by incrementally increasing its size. With new alloys with different moduli, it is the combination of size and modulus that determines the stiffness of the wire, not the size alone.[42] Box 28-4 recapitulates the requirements for effective torque transmission with the straight wire technique.

In summary, it is clear that torquing with the straight wire technique and without the use of auxiliaries requires large cross section, stiff (stainless steel) wires or NiTi wires with a pretorque of almost 40 degrees of activation, stiff and hard bracket wing and wire surfaces, and an inelastic ligating medium, with minimum relaxation with time.

BOX 28-5 Clinical Factors with Titanium Brackets

The reduced hardness of titanium brackets imposes several unfavorable implications in sliding and torquing with harder alloys such as stainless steel wires, and thus their use should be limited to cases of proven allergic reaction to nickel.

Titanium Brackets

The introduction of Ti brackets was based on the biocompatibility and lack of allergenic elements such as Ni in these appliances. The results of the limited available evidence on Ti brackets indicated that there are substantial structural differences in composition, structure, and manufacturing processes among currently available Ti brackets. These have been found to be single-piece appliances or two separate parts joined together by laser welding, composed of Ti, with a Vickers hardness close to grade II commercially pure (cp) Ti or of a Ti alloy type (Ti-6Al-4V).[43]

These brackets present differences in hardness, which in general is much lower than the stainless steel and NiTi archwire alloys. This difference in hardness may have significant effects in the wear phenomena encountered when an activated archwire is engaged into the bracket slot. NiTi archwires possess a hardness on the order of 350 to 400 VHN, whereas a stainless steel wire's hardness can be as high as 600 VHN. Box 28-5 notes the clinical implications of reduced hardness of Ti brackets.

This may induce increased wear rate during orthodontic treatment. It is well known that pure Ti and its alloys have poor wear resistance and require surface modification treatments before being used for biological applications. The use of Ti-6Al-4V alloy with a friction coefficient of 0.28 may have different frictional coefficients from the values available in literature because the latter have been calculated for the cp Ti friction coefficient of 0.34.

The clinical significance of the hardness findings may pertain to the fact that a low-hardness wing component may complicate the transfer of torque from an activated archwire to bracket. The low-hardness induced wear may preclude a full engagement of the wire to the slot walls and possible plastic deformation of the wing. Thus, whereas Ti brackets may be a viable alternative in the rare cases of proven allergic reaction to Ni-containing products, their reduced hardness may be implicated in wire binding in the slot during mechanotherapy.

Ceramic Brackets

Ceramic brackets were introduced for superior aesthetics, but there are several issues that arose from their large scale use. Most of the research efforts on this topic were focused on their fracture strength and debonding characteristics, following an unfavorable debonding pattern reported during the early 1990s.

The observation that ceramic brackets fracture frequently, usually at the wings and most often during debonding, is a universal, empirically derived knowledge for most readers. But why do these wires fracture clinically at rates much higher than the ones based on laboratory tests?

Brittleness and Fracture. We shall first provide substantiation for the brittleness of ceramics. These materials are composed of atoms bound together with such strong forces that their flexibility is notably impaired. As a result, the application of a force on ceramics leads only to a minimum elastic deformation with absence of permanent deformation. It follows that these materials maintain their dimensions and shape after fracture because no deformation has set in: this is why broken pieces of china can be glued together. In contrast to this effect, metals and polymers can absorb some of the energy provided during load application by altering their shape or dimensions, thus presenting ductile fracture. The bonding energy and their strong directional characteristics are what make these materials unable to deform. Also, the atomic packing factor in these materials is high, implying that a dense distribution of atoms in a three-dimensional array results in a high crystal density. Therefore, no plastic deformation of the wings is possible, and when the force exceeds a certain value, the wing fractures.

Nonetheless, the foregoing discussion fails to explain the observed higher rate of ceramic fractures clinically compared with that expected from laboratory studies, where ceramic brackets seem to pass the tests. Figure 28-4 illustrates a fractured ceramic bracket.

The mechanism underlying this effect was proposed by Sir Griffith in the early 1920s, when he provided substantiation to the noted deviation of the theoretical strength of ceramics from experimentally estimated strength.[5] Ceramic brackets, like most brittle ceramics, include manufacturing process–induced defects in the form of voids or microcracks, which are most visible in

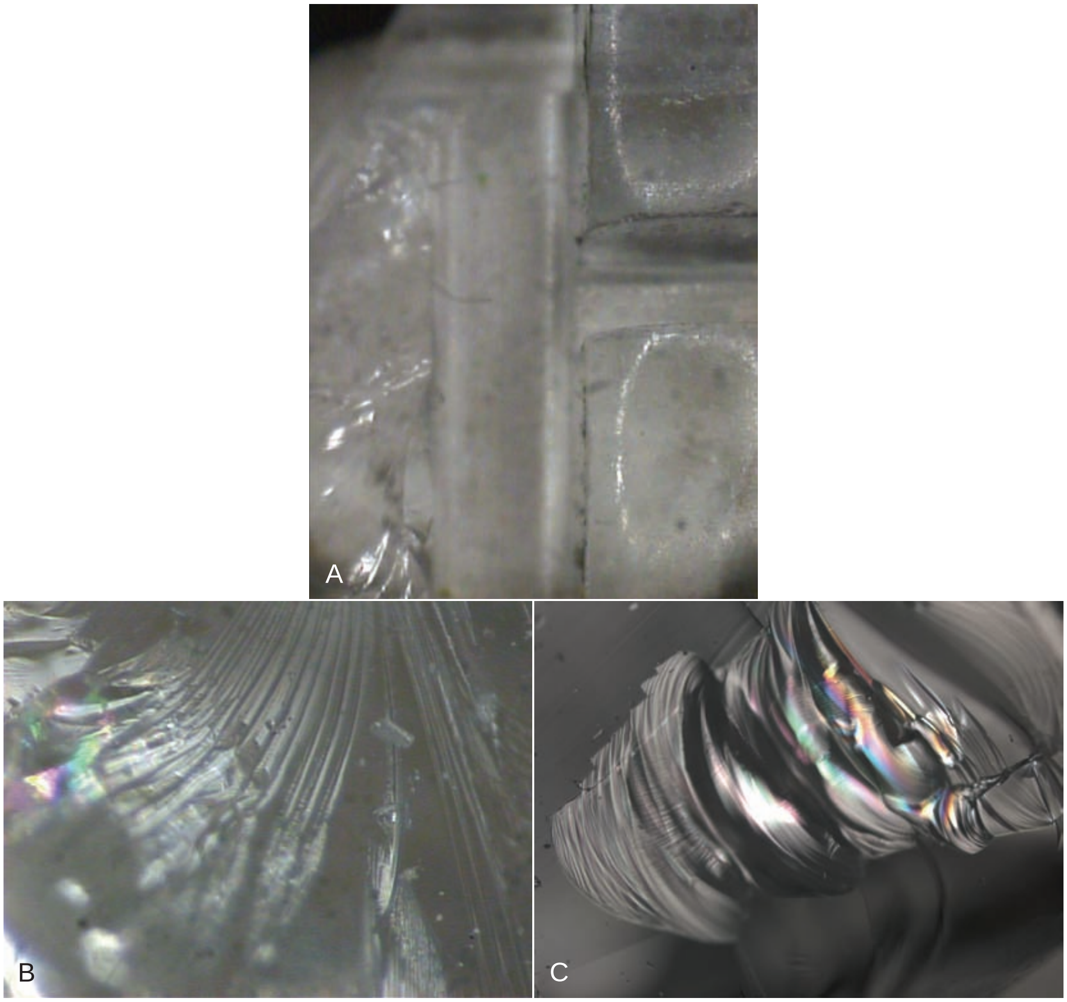

FIGURE 28-4 Optical light transmission image of a ceramic bracket showing a fractured wing **(A).** The radial pattern corresponds to the fracture plane **(B). C,** Under a dark field mode, the dramatic surface effects in **(B)** are shown.

everyday utensils, when glassware subjected to many cycles of dishwashing is examined under bright light. These defects tend to expand when the material is subjected to tensile stresses, where they “close” when compressive stresses are applied—hence, the higher strength of ceramics to compressive forces.

Factors that predispose to crack growth and fracture include manufacturer-controlled and operator-dependent variables; the former relates to the design of the bracket with the presence of many sharp edges and corners enhancing this phenomenon acting as stress raisers, whereas the latter relates to the accidental contact with instruments or burs, which initiate crack growth and propagation.

Ceramics in Wet Environments. Apart from the foregoing discussion, the exposure of ceramics or brittle materials to wet environments may further contribute to the reduction in strength. Assuming a brittle material, the critical stress (σ_{crit}) to induce fracture in a material with crack of size *c* can be expressed as

$$\sigma_{crit} = (2E\gamma/\pi c)^{1/2}$$

where *E* is the modulus of elasticity and γ is the critical surface tension of the brittle ceramic.

When this material is exposed to a wet medium (i.e., water or saliva), the previous equation of the critical stress is altered because the critical surface tension (γ) of the material is the only variable that is altered; actually, it is reduced. Because γ is on the nominator, it follows that a reduction in γ will result in a lower value for the whole term and thus the new critical stress would be decreased relative to one corresponding to the dry state. That means that when the ceramic brackets come into contact with water, their fracture strength is decreased.

Experimental work published in the field has verified this proposal, demonstrating that alumina (aluminum oxide) and zirconia (zirconium oxide) show decreased fracture toughness, faster crack growth rate, and reduced bending strength when they are exposed to water, normal saline, or Ringer’s solution.[4] The presence of electrolytes, enzymes, flora, and other factors may further increase the detrimental impact of aging on strength.

Effect of Grain Size. Last, the different behavior of polycrystalline ceramic brackets compared with the single-crystal appliances to crack growth is attributed to the fact that the crack is impeded at the grains boundaries of the former, where cracks propagate easier in the latter. It is interesting to note that the same reason for the superb aesthetics of single-crystal brackets arising from their high light transmittance, associated with a reduced light scattering owing to the lack of grain boundaries, is also responsible for their reduced fracture toughness. Accordingly, the size of grains may also play a role in determining fracture properties of ceramics: the ones possessing small grain size tend to favor the initiation of crack because the increased packing capacity of grain boundaries allows for the initiation of the crack in the periphery of force application. As the crack progresses, it has to bypass a dense network of grain boundaries, which act as crack inhibitors because some of the driving energy of the crack is dissipated at the boundary.[5]

On the contrary, large-grained ceramics show a higher resistance to crack initiation because the presence of crystals at the front of crack initiation does not favor crack formation. When the crack is initiated, there are fewer boundaries to inhibit its propagation and thus their fracture toughness is lower than that of their small-grain counterparts.

ARCHWIRES

Clinical Impact of NiTi Archwire Properties

The materials chapter in the previous edition of this book clarified the concept of phase transformation of superelastic NiTi wires. In the current edition, this section will deal with the actual impact of these crystallographic changes on orthodontics. NiTi archwires have become an integral part of orthodontic treatment because their low load-to-deflection ratio provides a desirable force level and better control of force magnitude.[42] Their initial classification included three categories: superelastic, nonsuperelastic, and true shape memory. This classification was confusing with respect to the meaning of the terms, and as a result, an alternative, structure-based classification was proposed by Kusy as (1) martensitic stabilized, which shows a stable martensitic structure, and thus no shape memory or superelasticity is expressed; (2) martensitic active, also termed thermoactive, in which an increase in the temperature leads to the transformation of the martensitic back to the austenitic structure; and (3) austenitic active, which demonstrates a pseudoelastic behavior, where the martensitic structure transformation of these alloys is stress induced, resulting from the activation of the wire. The words *martensite* and *austenite* are named after two prominent metallurgists, Adolf Martens and Sir William Chandler Roberts-Austen, respectively.

The majority of studies investigating the mechanical properties and structural conformation of NiTi wires have used three main routes to elucidate certain aspects of the wire structure and performance.[44–48] The most commonly used method consists of deflection curves, or cantilever testing of segments of archwires under various loading patterns. A problem with this method may be that superelasticity is, by definition, a property referring to the crystallographic structural elements of the material, and depending on the mechanical test, the response of the wires to loading may differ. Also, it is possible that nominally identical curve patterns are derived from different crystallographic structures.

On the other hand, x-ray diffraction studies of archwires are limited by the inherently near-surface nature of this technique, which shows a 50-micron penetration depth, thus providing evidence for the surface layers of the material. Alternatively, differential scanning calorimetry (DSC), which in principle determines the enthalpy for structural transformations, can provide information about the bulk material.[48]

Apart from the limitations on the analytical tools used in relevant research, there is some skepticism over the fact that the actual clinical performance of these wires in the intraoral environment has not been studied to the same extent as their mechanical properties.[49] Studies assessing the rate of tooth movement during treatment using different archwire alloys showed no significant differences among superelastic, nonsuperelastic NiTi wires, and multistranded stainless steel wires.[50] Last, many superelastic wires have been found to exhibit no superelastic properties in vivo, or at least no advantage over nonsuperelastic NiTi wires, because of the exceedingly high force level at the plateau, which is not seen in clinical conditions.

Superelastic and Nonsuperelastic NiTi in Crowding Alleviation. A recent randomized controlled clinical trial has reported no difference in the duration of alignment CuNiTi thermoactive archwires and NiTi wires.[34] This finding, which verified previous clinical research, was attributed to two potential factors: an alteration of transformation temperature ranges occurred in vivo, limiting the transformation of NiTi archwires; or the overall irrelevance of laboratory-derived mechanical behavior of wires to the loading conditions under clinical conditions.

The first hypothesis uses the effect of oral cavity conditions as a key variable affecting the clinical performance of wires. Intraoral aging is known to impose significant morphologic and structural alterations, including destruction of the structural integrity of NiTi wire, delamination, formation of craters, and increased porosity. Although many studies have highlighted the alterations of wires in vivo, the sole evidence on the effect of intraoral conditions on transformation of CuNiTi wires derives from a single study, which assessed the DSC parameters of intraorally exposed and as-received wires.[51] This investigation reported no difference between as-received and clinically retrieved wires in key variables related to phase transformation, except for a significant reduction in heating enthalpy associated with the martensite-to-austenite transition in the 27°C CuNiTi archwires. Therefore, the lack of difference between NiTi and CuNiTi specimens cannot be assigned to intraorally induced changes in the phase transformation pattern of the latter.

The temperature sensitivity of superelastic NiTi wires indicates that variations in mouth temperature could cause a stress fluctuation in NiTi wires during orthodontic treatment. An interesting protocol used to evaluate the effects of temperature changes on the mechanical properties of NiTi wires involved the examination of the response of NiTi wires at constant temperature and stepwise temperature changes from 37° to 60°C and back to 37°C and from 37° to 2°C and back to 37°C.[45] It was found that the load expressed by the superelastic NiTi wires increases on heating and decreases on cooling. Interestingly, in the stepwise temperature changes on heating, the load measured at body temperature as the final step was much higher than that measured at 37°C as an initial step. Also, cooling of wires induced transient effects in its deactivation phase but prolonged effects when the wire was tested in the activation phase. In contrast, the effect of short-term heating showed the opposite pattern.

Evidence indicating the dependence of mechanical properties of superelastic NiTi wires on temperature changes has also been presented by others, using a different approach. True shape memory wires continued to exert subbaseline bending force after short-term application of cold water, and this effect remained even after 30 minutes of postexposure restitution. In addition, it has been indicated that annulling of this effect required a temperature increase to about 50°C through intake of a hot drink.

An alternative hypothesis pertains to the differences of loading conditions between the laboratory conditions and the oral cavity. In general, loading of the NiTi archwire arising from its engagement into the bracket slot walls presents a much different pattern than free NiTi wire segments subjected to three-point or cantilever bending. The unique character of loading during engagement is due to the presence of free play or slack between the archwire and the slot.[37] Such a pattern cannot be simulated in laboratory configurations and may differentiate the performance of the material. This effect, along with the unrealistic force variants at which plateau levels are reached in the stress-strain curve of NiTi wires, may preclude the expression of the full spectrum of properties of NiTi archwires. Box 28-6 summarizes the reason for absence of clinical effects from crystallographically different NiTi wires.

Aging-induced alterations of interest to these applications include surface modification of the bracket slot or wire because of precipitation of calcified biofilm and formation of microparticles on the slot wall and wire surfaces and structural changes that might have a potent effect on the mechanical performance of material, particularly reduction in the modulus of alloys.

BOX 28-6 Effect of NiTi Structure on Clinical Parameters

The finding that no difference exists between CuNiTi and NiTi with respect to the duration of treatment implies that the loading pattern of wire inside the slot does not allow for expression of superelastic properties either because of aging or free play. It seems that crystallographic structure of materials possesses little importance in clinical outcome.

The foregoing considerations, coupled with the complexity of the oral environment, might explain the results of a study[50] on the effect of using archwires of different surfaces on the rate of space closure with sliding mechanics in vivo. Results from this investigation suggested that there was no difference with respect to the time required for space closure in vivo between conventional and ion-implanted beta-Ti wires.

PHOTOCURING AND ADHESIVES

Photocuring

Photocuring in orthodontic bonding has received wide acceptance because of the favorable characteristics of this technique, which include both material and handling advantages. Light-cured adhesives show decreased oxygen inhibition of polymerization, shorter polymerization reaction, and extended working time, which allows for extended handling in the positioning of bracket, thus being ideal for educational purposes.[52]

The development of various types of light sources for use in polymerization has resulted in a multiplicity of factors taking an active role in the polymerization kinetics of the polymeric material.

Light Intensity. When a light beam hits an orthodontic adhesive surface, the extent of light penetration into the relatively thin layer of material depends on a number of factors related to the light beam itself, the application mode, and the material characteristics. First, the distance of the source from the material surface and the path that the incident beam will have to travel to reach the adhesive have a large effect on the intensity of incident light.[53]

Likewise, the literature shows a wide array of studies from the field of restorative dentistry dealing with the effect of material composition on the light penetration and degree of cure. In general, the translucency of the composite, which allows for the penetration of light away from the light source, increases with an increasing matching of the refractive indices of the matrix and fillers. Matrix includes the co-monomer system of bis-GMA/TEGDMA mixture, which is used to facilitate the combined favorable features of both monomers, along with several other organic constituents such as polymerization inhibitors, initiators, colorants, etc.[54,55] The choice of these specific monomers is due to the increased molecular weight of bis-GMA, which offers stability and a thicker consistency, and the short-chained TEGDMA, which contributes to the larger degree of cure because of its decreased molecular weight and higher mobility. Varying the proportion of these constituents, as well as other materials such as amines, accelerators, inhibitors, and initiators, may slightly affect the refractive index of the matrix, which in methacrylate resins is about 1.5.[54]

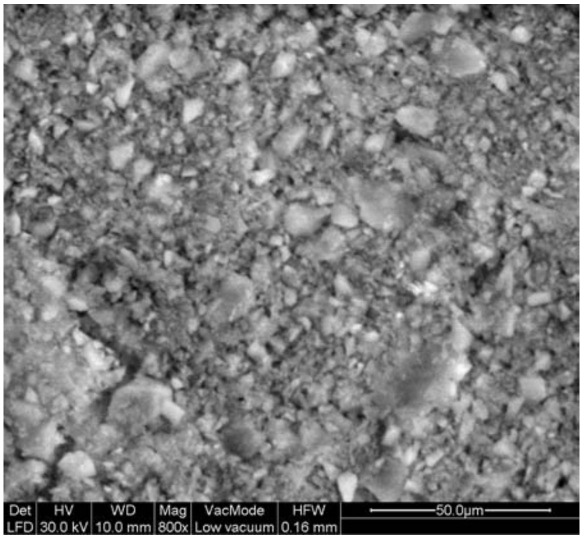

FIGURE 28-5 Secondary electron image of a ground light-cured orthodontic adhesive depicting the variability in filler size (original magnification ×800).

Fillers, on the other hand, which are contained in the adhesive in a ratio of 60% to 70% per weight in the form of silica particles and barium glasses, possess an index of 1.55 at the wavelength of the photoinitiator.[56] Figure 28-5 depicts the variability in filler size of an adhesive.

The evidence available in the field of composite resins suggests that maximum light scattering occurs at particle size equivalent of the half of the wavelength of a photoinitiator of the polymerization, which for camphorquinone is 468 nm. However, the typical picture of an adhesive includes a large size variation of the filler particles, which does not satisfy the set values for size. Also, the distribution of filler size in composites is designed to include favorable size, in contrast to orthodontic adhesives where most filler systems are placed arbitrarily.

Almost all the light-cured adhesives use camphorquinone as a photoinitiator of the polymerization. This molecule is contained in the resinous phase at a concentration of 0.2% to 1% of the matrix and shows a peak absorbance wavelength of 468 nm, which implies that increased light intensity in other frequencies may not be effective to excite the molecule.[54] This is an important factor that must be considered in the selection of lamps based on the peak intensity reported by the manufacturer; it is critical that this peak should correspond to the absorbance wavelength of the photoinitiator. Because of its yellowish tint and resultant undesirable matching in uncured versus cured materials, camphorquinone has been recently replaced in some composite resins by 1-phenyl-1,2-propanedione (PPD) with a peak absorbance in the area of 390 to 410 nm.[57] It follows that potential replacement of camphorquinone by PPD will result in a necessity for altering the effective peak wavelength of polymerization lamps due to the shift of the required wavelength of the new material. Studies looking at the effect of mixing of these two initiator systems have shown a synergistic action. At any rate, the orthodontic adhesive systems are not expected to alter their initiator systems because of the main reason for moving to this change—namely, the color mismatch between the unpolymerized and cured forms of the same material—is not of orthodontic concern.

Lamps. Light-cured orthodontic adhesives require a light-curing source with sufficient intensity and defined wavelength to initiate the polymerization reaction. Increased light intensity and curing time have been advocated for fast polymerization and high degree of cure.[58,59] Recently, various types of commercially available light-curing units have shown comparable bond strength values to that produced by conventional halogen lights at shorter irradiation times.[60] The wide array of new light curing sources includes plasma arc, laser, and LED lights, which were integrated in the profession to facilitate short irradiation times.

Plasma lamps present very high intensity compared to halogen lights (1600 to 2100 mW/cm^2), an effective spectrum of 450 to 500 nm, and a significantly higher cost, which nevertheless is counterweighed by their increased life span of 5,000 hours relative to 40 to 100 hours for halogen. Orthodontic bonding with these light sources can be achieved with only 6 seconds of irradiation for stainless steel brackets or 3 seconds for ceramic brackets.[61]

Laser lights show an intensity of 700 to 1000 mW/cm^2, with a basically monochromatic spectrum of variable wavelength (454, 458, 466, 472, 477, 488, and 497 nm) and are costly but have an almost infinite life span. Application of these light sources to orthodontic bonding has shown that 5 seconds of irradiation provided bond strength values comparable to those found for halogen.[62]

Light-emitting diode (LED) curing units yield a maximum intensity of 1100 mW/cm^2 at a spectrum of 420 to 600 nm, have a cost comparable to that of conventional halogen lights, and possess a nearly infinite life span, while offering handling advantages with cordless photocuring option. The results of bond strength studies show contradictory evidence on the performance of these lights, with most investigations demonstrating comparable bond strength to halogen lights at the same irradiation duration and reduced strength when shorter time frames are applied.[59,63–65] Conventional bond strength protocols have not been proved to be clinically relevant,[66] and therefore, care should be exercised in extrapolating laboratory results to a clinical situation.

Biological Properties of Blue Light and Adhesives

Apart from standard cytotoxicity assays reported in the literature, the use of high-intensity curing lamps and polymeric molecules has given rise to the investigation of potentially unfavorable effects relevant to orthodontic treatment, which could be proved hazardous to the patients and treatment provider. These include the effect of blue light on mucosa, the action of ground adhesive particulates at debonding as aerosol, and the examination of the role of bis-GMA–based adhesive resins as endocrine disruptors.

Blue Light Effects. Although initially blue light was characterized as relatively harmless, more recent studies have shown that it affects several aspects of cell physiology. Particularly, it has been reported that it disturbs mitochondrial function, thus causing an oxidative stress leading to activation of the stress-responsive pathways.[67] The group of investigations cited earlier suggested that blue light induces effects on the DNA integrity, cellular mitosis, and mitochondrial status in various cell types through the generation of reactive oxygen species (ROS). Investigations in the field have used a variety of mouse and human, normal and transformed cell types, as well as a vast array of assays, which extended from assessment of cell vitality to markers of cell metabolism and oxidative status. This multiplicity of testing protocols has resulted in a variety of effects described.

The result of the sole investigation adopting the time exposures seen in an orthodontic routine bonding[67] has shown that blue light did not affect the viability of these cells, and no immediate effect on the regulation of proliferation was noted 24 hours after irradiation. One week after treatment, however, all types of irradiation induced a significant inhibition of cell proliferation compared with untreated cultures.

The source of this effect has been the subject of several investigations, which have reported that exposure to blue light leads to the generation of ROS, proposing that these are responsible for the adverse biological effects of blue light. However, in a study using a simulation of photocuring in orthodontics,[67] the use of a potent antioxidant agent did not annul the inhibitory effect of irradiation on cell proliferation.

In summary, there is evidence that the biological effects of blue light are confined to long-term effects, and are not mediated by oxidation mechanism or DNA damage. The array of effects described suggests that high energy sources such as plasma lamps should be used with caution, especially when bonding mandibular tubes where a close contact between the tissue and the lamp tip occurs.

Grinding of Adhesives: Production of Aerosol and Estrogenic Action. A recent review on the subject has presented the potential action of orthodontic adhesives as endocrinologic disruptors and summarized the available evidence.[52] A substantial body of literature has demonstrated the cohort of phenomena accompanying the exposure of organisms to bisphenol-A (BPA).[68] The reported action covers a wide spectrum of effects at the tissue, organ, and system level, such as higher risk for breast cancer in females and prostate cancer in males; induction of calcium influx, which leads to prolactin release and associated behavioral effects; and development of hyperglycemia and insulin tolerance.[69–71] The basic differences between the study of common toxicants or other hazardous materials and BPA relate to the fact that natural hormones such as 17β-estradiol induce effects at concentrations far beneath the levels at which all hormone receptors become bound. Once all receptors are occupied, a further increase in natural hormone levels does not result in an increase in response. Conventional testing of substances for toxicologic impact assessment involves exposure to levels many times higher than those required for complete receptor binding. Thus, the lack of response to excessively high concentrations of effectors in relevant investigations may be misinterpreted as a lack of effect. Moreover, the effects of BPA on tissues follow a nonmonotonic curve pattern, which is characterized by intense reactivity at low levels and no response at very high ones, respectively.[71] Last, the concept of "critical concentration," referring to the required amount of substance to induce effects, may not apply in the case of exposure to BPA.[71,72]

In orthodontics, the removal of the brackets and cleanup of the enamel surface that follow the completion of orthodontic treatment involve grinding of the adhesive layer with rotary instruments at low or high speed. The aerosol produced by this process contains polymer matrix and filler degradation byproducts as well as particulates arising from the wear of bur. Figure 28-6 illustrates the morphologic condition of particulates produced after the use of rotary instruments on an adhesive.

The potential hazardous nature of aerosol is two-fold: first, it relates to the production and circulation of a dust with a sufficiently small aerodynamic diameter to reach the alveoli of the lungs.[73–75] Therefore, concerns may arise regarding the respiratory health of the patients and, most important, the treatment provider and staff, who are exposed on a long-term basis to these conditions. Long-term exposure to this type of stimuli establishes pathology, as has been shown from large epidemiologic studies from urban or industrial areas with increased air particulate content. Second, there is a potential hormone-disrupting action of these particles derived from the presence of a double benzoic ring in the bis-GMA monomer, which, under specific conditions, has been reported to lead to the formation and release of BPA.[76–78]

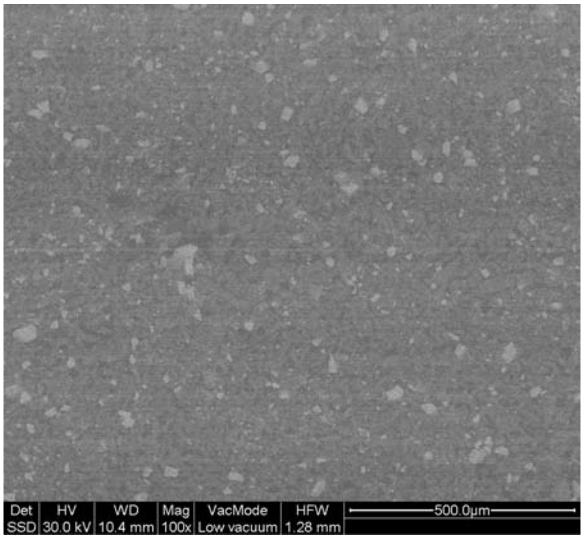

FIGURE 28-6 Backscattered electron image of the particulates of a chemically cured adhesive produced by grinding as occurred during debonding (original magnification ×100).

Whereas bulk, intact orthodontic adhesive specimens have not demonstrated BPA release or estrogenic action,[79,80] the biological properties of particulates examined with a standard in vitro assay[81,82] have shown opposite effects.[78] Grinding, especially without water spray, increases the temperature locally, with unpredictable effects on the composition and formation of resin byproducts, while, concurrently, this process dramatically increases the effective surface area of the material with host tissues, enhancing the reactivity of the material, with potentially altered outcome on the tissue–material interactions. In the broader biomedical literature, the difference between the biological properties of bulk materials and their particulates has been established for inert alloys such as Ti.[82]

Box 28-7 notes the potentially estrogenic action of adhesive in a particulate form.

Grinding of the adhesive introduces heat into the material, exposing the matrix to severe heat shock and mechanical aging. It has been long known that grinding and polishing increases the C–C bonds conversion to C=C on the surfaces of resin composites mainly due to the heat produced. The chemical alterations induced in the abraded powder compounds possessing double benzoyl rings, including bis-GMA, are unknown. It may be hypothesized that this procedure may accelerate or induce formation of BPA, with endocrinologic disruption as an outcome.

This finding is of interest considering that receptors for estrogen have been identified in human gingival tissues, and thus this tissue can be a target organ for sex hormones.[83,84] It has been reported that oral mucosa of premenopausal women was significantly more sensitive to sodium lauryl sulfate in toothpastes than that of

BOX 28-7 **Estrogenic Action of Adhesives**

Grinding of the adhesive at debonding results in a two-fold hazardous sequalea: generation of particles, which act as an aerosol with detrimental action on the respiratory system; and potential estrogenicity, owing to the incorporation of Bis-GMA monomer, which gives rise to bisphenol-A formulation with xeno-estrogenic properties. It is interesting to note that no release of bisphenol-A and no estrogenicity have been reported for chemically cured and light-cured adhesives when they are not ground.

postmenopausal women.[85] This might indicate a sex hormone influence on the oral epithelium reactivity to chemical challenge.

Because a given day in practice may include several appointments involving removal of bonded orthodontic appliances, the treatment provider, patients, and staff are exposed to substantial amounts of adhesive aerosol on an almost daily basis. Care should be taken to apply preventive measures such as mask and protective glasses, access to fresh air, and use of suction. Future research should include testing of other bis-GMA–containing dental polymers that are subjected to grinding during clinical conditions, including composite restorative resins, to clarify the presence of potential effects.

SUMMARY

This chapter analyzed selective aspects of orthodontic materials with direct implications in mechanics, treatment duration and hazardous nature of materials, and applications to patient and care provider. The effects of manufacturing processes and specific mechanical properties on key characteristics of brackets that may alter treatment mechanics were listed. The low hardness of Ti brackets was reported along with the expected undesirable effects on mechanics, and the brittleness of ceramic brackets was substantiated and explained.

In the section on archwires, the actual clinical effects of superelasticity were questioned, with evidence providing no change in treatment duration for superelastic and nonsuperelastic wires; the potential source of this discrepancy between laboratory and clinical studies was highlighted.

Last, in the adhesives section, the use of modern lamps and their advantages were analyzed and the fundamentals of photocuring were presented. The biological action and hazardous nature of three issues were covered, including the effects of blue light on mucosa, the action of adhesive particles produced during grinding at debonding as aerosol, and their reported estrogencitity.

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CHAPTER 29

Searching for Evidence in Clinical Practice

David Turpin, Greg Huang

OUTLINE

Introduction to the Evidence-Based Practice
Levels of Evidence
Conducting a Search
Asking the "PICO" Question
Systematic Reviews and Meta-analyses
Clinical Topics with Varying Levels of Evidence
  Self-Ligating Brackets
  One- and Two-Phase Treatment for Class II Skeletal Problems
Ethical Considerations for the Evidence-Based Practice
The Individual Practitioner
The Professional Association
The Orthodontic Manufacturer/Supplier

Edward H. Angle lived life to the fullest, inventing new appliances, conducting clinical research, and teaching. His views were most influential in an era when people tended to look to the experts for guidance in all matters of life. When Dr. Angle died in 1930, no one stepped forward to continue his school of "orthodontia" as had been established in Pasadena, CA.[1] From that time on, the teaching of orthodontics gradually moved into existing dental schools, and we entered the "Age of Education." With the beginning of World War II, scientific innovation flourished out of necessity as entire countries underwent tremendous advances and development in an effort to respond to challenging new conditions. Scientists who migrated to new countries found opportunities to develop new medications, surgical techniques, sources of energy, etc., and we entered the "Age of Science.' Although it was thought to be the "end all" for the health care professions, such was not the case. As the public became better informed, many of the accepted ideas in medicine and dentistry were called into question, opening the door to what many now call the "Age of Evidence."

INTRODUCTION TO THE EVIDENCE-BASED PRACTICE

Evidence-based dentistry (EBD) is an approach to oral health care that requires the judicious integration of (1) systematic assessments of clinically relevant scientific evidence, relating to the patient's oral and medical condition and history, with the (2) dentist's clinical expertise and the (3) patient's treatment needs and preferences.[2]

LEVELS OF EVIDENCE

Hierarchical rating systems exist to grade individual or multiple studies based on the type of study design and their effectiveness in answering a specific question.[3] The "hierarchy of evidence" places great emphasis on factors that should minimize biases, while providing valid results. Some of these factors are selection of subjects, assignment to treatment arms, blinding, and control of confounding factors (Figure 29-1).

Meta-analysis and systematic reviews of randomized controlled trials constitute the highest levels of current best evidence, while expert opinion is the lowest level of evidence. A systematic review of the existing evidence provides us with the current best information for a specific clinical question.

It should be remembered that the term *evidence-based* is always closely associated with patient care or treatment outcome—thus, the most appropriate term to use is *evidence-based practice*, in lieu of *evidence-based research*. This is because its primary purpose is to improve patient care. Evidence-based practice calls for integration of the highest levels of research evidence along with clinical expertise and patient values. It does not replace clinical skills, judgment, experience, or

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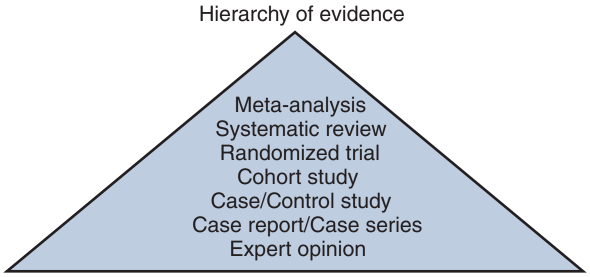


FIGURE 29-1 Examples of evidence ranging from best to worst, *top to bottom.*

patient preferences, but provides another dimension to the traditional decision-making process. More simply stated, the use of an evidence-based approach to clinical practice is intended to close the gap between what is known and what is practiced; to improve patient care based on informed decision-making. An evidence-based practice always consists of three components or legs of support. First, of course, treatment procedures are based on the "best available evidence." Discussion around the treatment of specific orthodontic problems will clarify how to search for the highest level of evidence, or what to tell the patient if there is very little evidence for a proposed treatment. The second leg of support calls for a doctor's education and experience in the decision-making process. And last, your patient's preferences and values form the third leg of support. All three are critical in making the best, evidence-based decisions.

CONDUCTING A SEARCH

Where you search for information may influence the quality of advice you receive. For instance, one may look for information that is posted on the web. Many websites provide little oversight over the material they post, so information may or may not be accurate. On the other hand, there are other sites in which information is highly reviewed and/or refereed, and this information is updated as the knowledge base changes. The Cochrane Collaboration comes to mind as having a well-deserved reputation for maintaining the highest standards in summarizing evidence that is of the highest quality.[4] Likewise, journals come in all flavors, some not refereed at all, some "lightly" reviewed, and some highly refereed by experts in the field. Only a few orthodontic journals have a respected Impact Factor (IF), and this is usually due to a thorough peer-review process that strives to identify and publish only the most meritorious work. The quality of material published in most other venues can drop off quickly if a rigorous review process is not in place.

PubMed provides an opportunity to easily conduct searches of most current journals, even in fields other than orthodontics.[5] Once references are identified, university students or faculty members usually have access to many publications via their university affiliations. This privilege is available through the "institutional" subscription paid for by the university. Although "open source" for all published scientific journals is something appealing to scholars and some publishers, it is still not universally available. Someone still has to pay the cost of publishing scientific findings. Options include charging the authors for every page published, while others favor advertising. Banner advertising is the most common type, but in the future it may be common for publishers to electronically push groups of articles that have common interest to specific subscribers … all paid for by commercial entities. As long as the advertisers do not select the articles, this convenience to readers is considered ethical. Many organizations already select and screen studies of the highest level in specific fields to provide to members of the organizations. They might be notified by e-mail every month or whenever another study is added to the collection. The American Dental Association (ADA)[6] and the American Association of Orthodontists (AAO)[7] provide this member service, as do the librarians of most universities and scholarly organizations.

Evidence-based clinical recommendations are developed through critical evaluation of the collective body of evidence on a particular topic to provide practical applications of scientific information that can assist orthodontists in clinical decision-making. In addition to scientific journals, dental schools, and approved courses, sources of this information may be found in the following locations:

1. PubMed[5]

   The National Library of Medicine's searchable database of more than 12 million indexed citations from more than 4600 medical, dental, health, and scientific journals
2. Cochrane Collaboration[4]

   An international nonprofit organization that develops evidence-based systematic reviews on health care interventions
3. ADA Center of Evidence-Based Dentistry[6]

   A resource for evidence-based dentistry that is periodically updated and accessible to dentists and the public. It houses guidelines and collections of systematic reviews for general dentistry, as well as specialty areas. It also provides critical summaries of systematic reviews.
4. Websites for various dental specialty organizations

   An example is the evidence-based website that the AAO Library[7] maintains at its member website.

ASKING THE "PICO" QUESTION

Knowing how to ask the right question is the start of every search for evidence. One method of specifying a research question is often referred to as asking the "PICO" question.

- What is the **P**roblem or Population you wish to investigate?
- What **I**ntervention do you propose to use?
- Are you **C**omparing different treatment methodologies?
- What is the **O**utcome that will be assessed?

The key is to develop a very specific clinical question prior to conducting the search of all potentially useful databases. Regarding the "problem" to be treated, your description should be fairly specific, with inclusion of the most important characteristics of the population of interest. If treating a patient with crowded mandibular incisors, how much crowding is necessary in order for a patient to be included in the study? Can the patient have any other alignment problems, etc.? The "intervention" might call for the use of fixed orthodontic appliances or something less complex. The comparable procedure being considered might concern the need to extract one mandibular incisor or to attempt nonextraction treatment. Other variations may have to be considered such as interproximal stripping to create the needed space for alignment. And last, what is the outcome that will be assessed? How will alignment of the mandibular teeth be measured, and is long-term stability of interest? Summarizing this exercise for the fictitious patient with a chief complaint of "lower tooth crowding," you might arrive at the following PICO chart and question:

Problem/Population:	Adults with lower anterior crowding
Intervention:	Nonextraction treatment
Comparison:	Treatment with lower incisor extraction
Outcome:	Occlusion, Stability of alignment
PICO Question:	For adult patients with moderate to severe mandibular anterior crowding, does nonextraction treatment, compared with extraction of a lower incisor, result in equivalent occlusal outcomes that are stable in the long term?

After specifying the PICO question, the clinician is ready to conduct a computerized search with maximum efficiency for finding the best evidence with which to answer the question. Inclusion criteria that are too broad may result in a large number of articles that will need to be discarded because they are not pertinent to the study. On the other hand, inclusion criteria that are too narrow may only retrieve a portion of the available and relevant evidence. When one group followed through with such a search of the literature on incisor extraction, a large number of case reports and case series studies were identified, but no randomized controlled trials or meta-analyses were found. Even if all of these studies were only case reports, they may provide useful information when higher levels of evidence do not exist, especially in situations where careful diagnosis, treatment planning, and wax set-ups indicate realistic options (Figures 29-2 to 29-7).

The additional effort required to develop an evidence-based practice is a viable and desired goal for the orthodontic practitioner. But flexibility and a good understanding of evidence-based practice are essential. For example, the mother of a 9-year-old girl with a Class II malocclusion presents for an examination. "She is constantly teased," recalls the mother, "and we both think something should be done now to improve her teeth." As an afterthought, she adds that the family plans to be relocating to Indonesia in about 18 months due to the father's commitment to an oil company. Even with the recent findings of several randomized controlled trials related to the timing of skeletal Class II treatment, you may not hesitate to propose early treatment in this situation because the parents see their child being teased excessively[8] or believe them to be at risk of traumatic

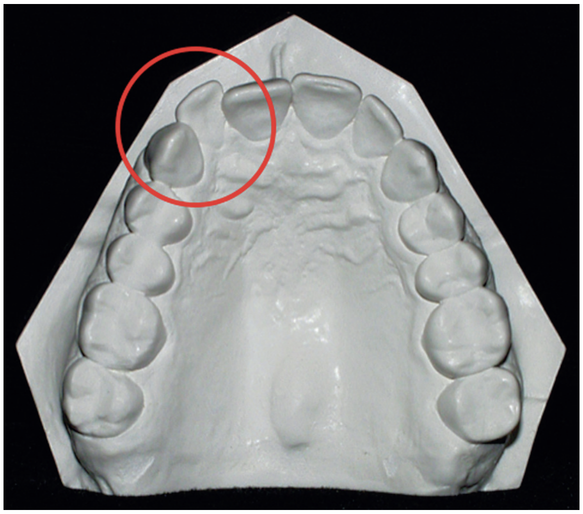


FIGURE 29-2 You are planning treatment for an adult patient with nearly 6 mm of mandibular anterior crowding. The chief complaint of the 37-year-old woman is dislike for a rotated maxillary right lateral incisor and "lower tooth crowding."

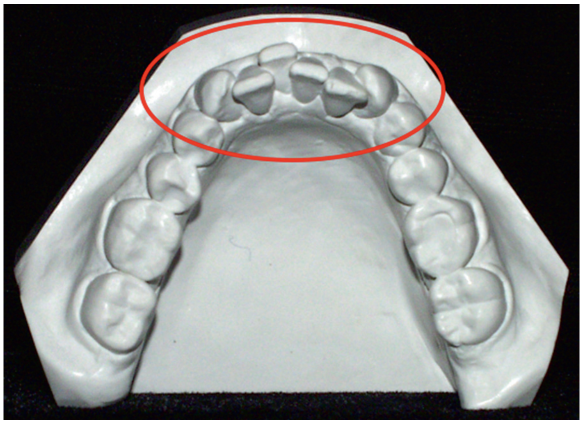


FIGURE 29-3 Note the pretreatment moderate crowding in the mandibular cast.

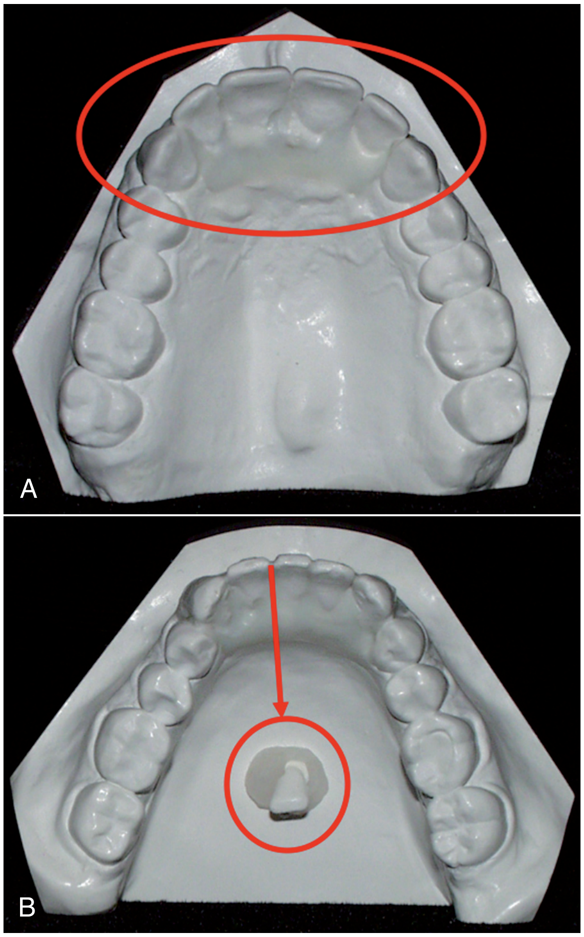


FIGURE 29-4 With a lack of high-level evidence in answer to the PICO question, experience plays a role. A wax setup with extraction of a mandibular central incisor reveals a possible solution to the crowding.

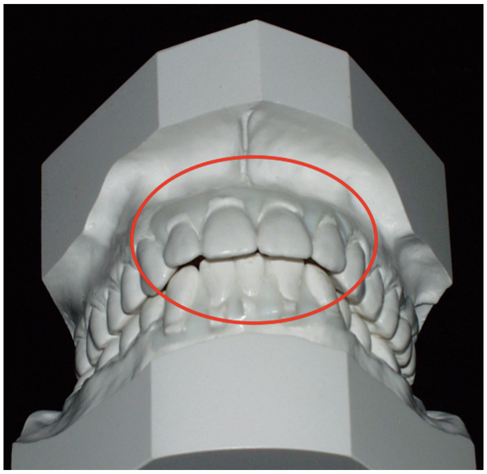


FIGURE 29-5 The incisor relationship with the setup seems to be acceptable with near ideal overjet and overbite.

dental injury.[9] Clinicians need to be reminded that an evidence-based practice includes recognition of patient needs and preferences as well as the doctor's clinical expertise and identification of the best available evidence.

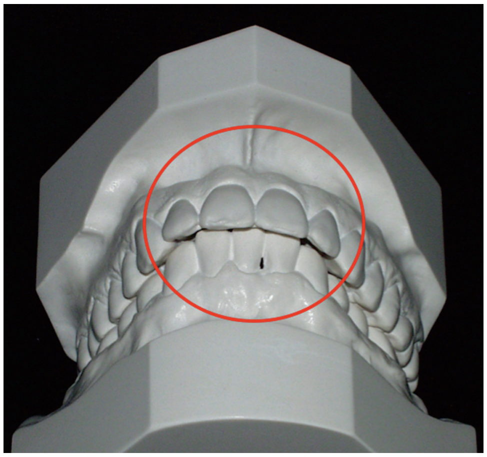


FIGURE 29-6 Posttreatment incisal relationship is identical to the wax setup, verifying the value of experience in selecting this plan of treatment.

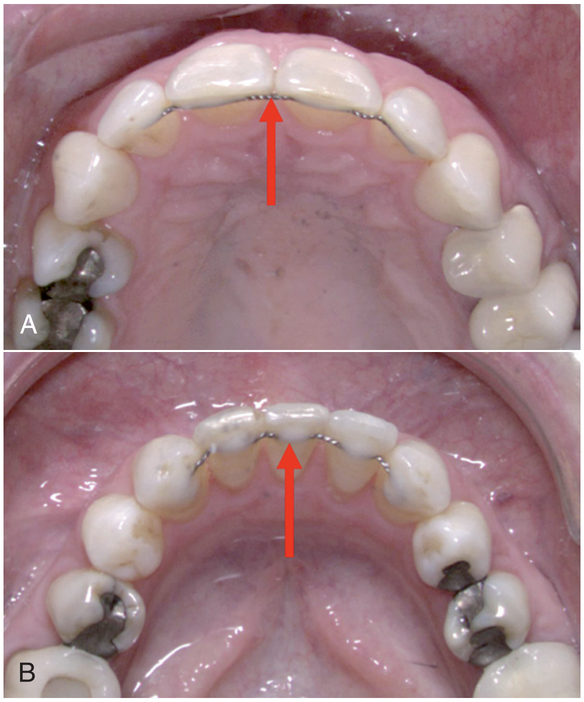


FIGURE 29-7 Bonded retainers are deemed necessary to maintain anterior alignment in both arches following 6 months of treatment.

It is also critical to remember that the merits of a systematic review may vary based on the quality of the included studies, so this aspect of quality needs to be carefully assessed. The inclusion of studies other than randomized trials may be necessary if randomized trials are scarce or absent. However, these studies should be carefully analyzed to determine if adequate measures have been taken to prevent biases from affecting the validity of the results. Many current treatment procedures appear to be successful in the short term, but long-term results are an important outcome and must become everyone's goal no matter how large the challenge. For this reason alone, it is critical to support research efforts designed to provide additional evidence needed to improve patient care.

SYSTEMATIC REVIEWS AND META-ANALYSES

The tremendous volume of information that is available today makes it difficult for any clinician to stay current on all orthodontic topics. Systematic reviews and meta-analyses are valuable resources to assist clinicians who wish to quickly locate the best evidence on a particular issue. Guidelines for the conduct of a systematic review have been published by the Cochrane Collaboration.[10] These methods are extremely helpful in producing thorough and clinically useful systematic reviews. The Cochrane Collaboration also provides software to perform statistical analyses of pooled data.[11] These statistical analyses are the distinguishing feature of meta-analyses because the other steps involved in meta-analyses are identical to those of systematic reviews. For this reason, systematic reviews are often considered qualitative assessments, whereas meta-analyses are quantitative evaluations. Meta-analyses may be inappropriate where heterogeneity in clinical, methodological, or statistical approach argues against combining studies. Most often, the results of meta-analyses are presented using forest plots (Figure 29-8). A forest plot is designed to illustrate the relative strength of treatment outcomes in multiple quantitative studies addressing the same question.

It was developed for use in medical research as a means of graphically representing the results of randomized controlled trials. Figure 29-9 provides an example

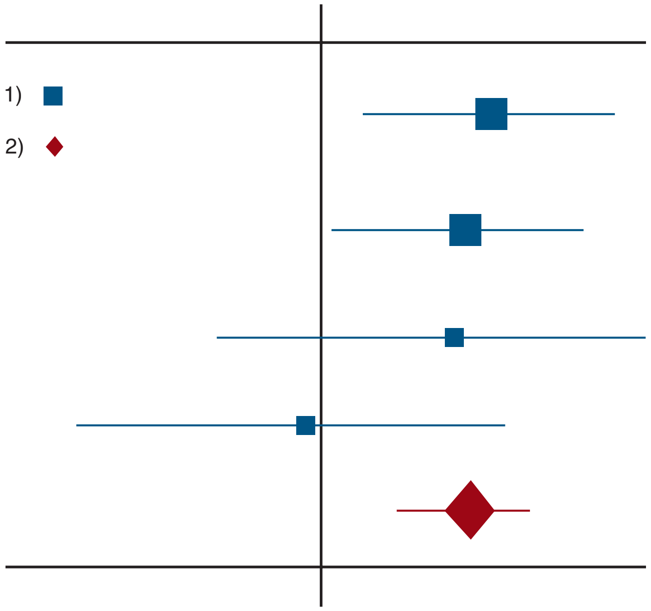
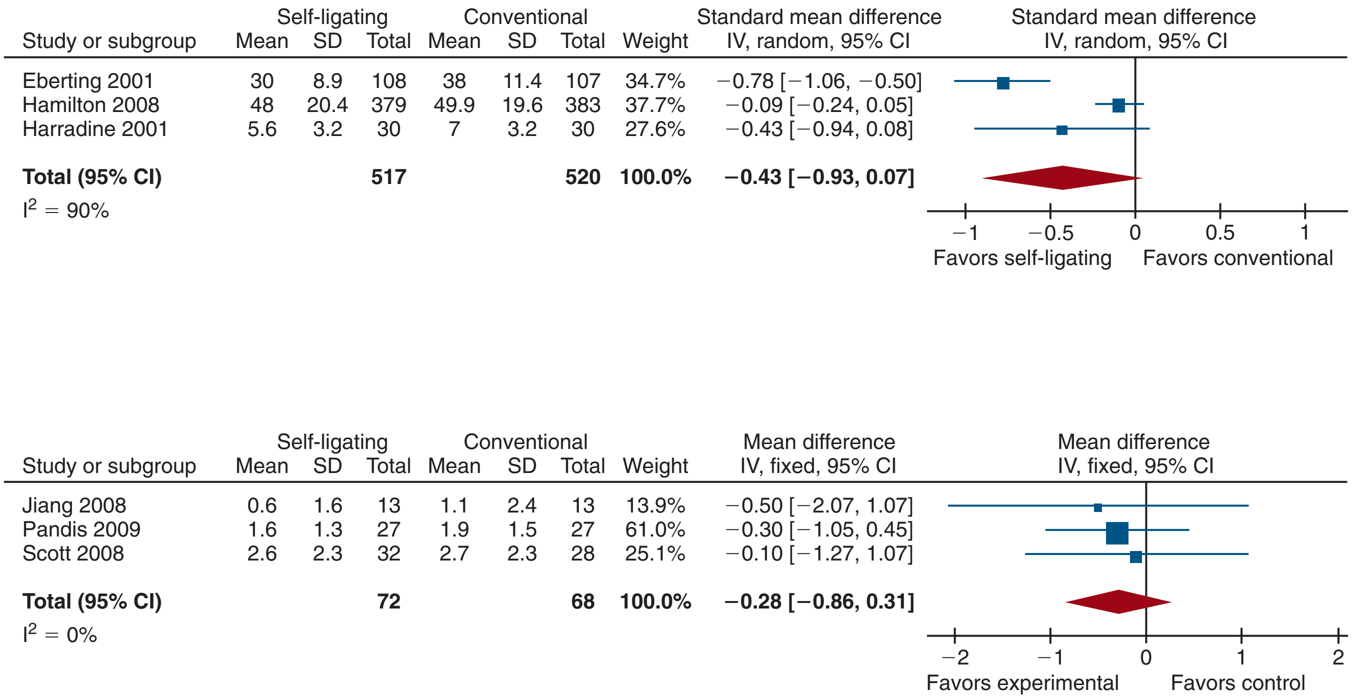


FIGURE 29-8 An example of a forest plot, comparing the results of four experiments (*squares*) and a meta-analysis (*diamond*), with confidence intervals. The *vertical line* shows no effect.



Study or subgroup	Self-ligating Mean	SD	Total	Conventional Mean	SD	Total	Weight	Standard mean difference IV, random, 95% CI
Eberting 2001	30	8.9	108	38	11.4	107	34.7%	−0.78 [−1.06, −0.50]
Hamilton 2008	48	20.4	379	49.9	19.6	383	37.7%	−0.09 [−0.24, 0.05]
Harradine 2001	5.6	3.2	30	7	3.2	30	27.6%	−0.43 [−0.94, 0.08]
Total (95% CI)			**517**			**520**	**100.0%**	**−0.43 [−0.93, 0.07]**
$I^2 = 90\%$								

Study or subgroup	Self-ligating Mean	SD	Total	Conventional Mean	SD	Total	Weight	Mean difference IV, fixed, 95% CI
Jiang 2008	0.6	1.6	13	1.1	2.4	13	13.9%	−0.50 [−2.07, 1.07]
Pandis 2009	1.6	1.3	27	1.9	1.5	27	61.0%	−0.30 [−1.05, 0.45]
Scott 2008	2.6	2.3	32	2.7	2.3	28	25.1%	−0.10 [−1.27, 1.07]
Total (95% CI)			**72**			**68**	**100.0%**	**−0.28 [−0.86, 0.31]**
$I^2 = 0\%$								

FIGURE 29-9 Examples of random-effects and fixed-effects forest plots. There are random- and fixed-effects meta-analyses that can provide similar or differing results, and initially both are employed in order to ascertain which format is best. Random-effects analyses are used most where there are likely differing treatment effects being assessed. Fixed analyses are used to evaluate a common treatment effect measured in a group of studies. The I^2 index value is a percentage of the total between-studies variability due to heterogeneity.

of how a forest plot can be used in a study of self-ligating brackets.

In Comparison 1 (see Figure 29-9), you can see that three studies have data that can be used to assess occlusal indices at the end of treatment for self-ligating compared with conventional appliances. Data are provided about the number of subjects, means, standard deviations, and standardized mean difference.* Standardized mean differences are sometimes used when the measurements used in various studies are not the same, and some statistical method is necessary to allow comparison and pooling of these different measures. In the graphical portion, the vertical line indicates no difference, while the area to the left of this line indicates that the experimental group performed better, and the area to the right indicates that the control performed better. In Comparison 1 (see Figure 29-9), each study's mean is indicated by the green square, and the horizontal line indicates the 95% confidence interval. If the horizontal line touches the vertical line, then there is no statistically significant difference for that study. At the bottom of the graph, there is usually a diamond, which indicates the overall mean and 95% confidence interval. Again, if this diamond touches the vertical line, the summary finding is not statistically significant. One final point deals with the use of a random-effect (Comparison 1) versus fixed-effect model (Comparison 2) (see Figure 29-9). A random effect model assumes that studies are measuring different treatment effects, and this "randomness" is accounted for in the calculation of the final point estimate and confidence interval. If you inspect the means and standard deviations for Comparison 1, you see there is little overlap of the confidence intervals of the three studies and that heterogeneity between the studies is high (indicated by a high I^2 value of 90%) (see Figure 29-9). When the $I^{2\dagger}$ value is 75% or greater, a random-effects model is generally employed. On the other hand, Comparison 2 indicates that all three studies have overlapping confidence intervals, and heterogeneity between the studies is low (I^2 value = 0). Therefore, a fixed-effects model was used. For a more comprehensive description of statistical methods related to meta-analyses, the reader is referred to the Cochrane Handbook for Systematic Reviews (reference #10).

CLINICAL TOPICS WITH VARYING LEVELS OF EVIDENCE

Every once in a while, as clinicians we are asked by patients or parents about various appliances or treatment approaches. For example, we have all been asked, "Are extractions necessary for my daughter?" "What is the advantage of early treatment?" and "Can we use 'invisible' braces to treat my crooked teeth?" A decade ago, patients would have had to either rely on the doctor's reply or extract this information themselves from journals. However, the Internet has changed all that, and the conclusions from many systematic reviews are now quickly and easily accessible via the Internet. Thus, practitioners need to be familiar with the available evidence, including the methods to access and assess this information. Two topics illustrating various levels of evidence are presented next.

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*The meta-analysis of differences between means from different trials relies on the outcome being measured in the same units in every trial: we cannot combine a difference in mean weight loss in kilograms with a difference in mean weight loss in pounds. If you know the multiplication factor to convert from one scale to another (e.g., how many pounds there are in a kilogram), then you should directly convert all the data to the same units. However, we cannot combine two different psychometric scales even if they both measure depression, because the multiplication factor is not known. A way around this is to compare standardized mean differences rather than actual means.

The standardized mean difference is the difference in means divided by a standard deviation. This standard deviation is the pooled standard deviation of participants' outcomes across the whole trial. Note that it is not the standard error of the difference in means (a common confusion).

The standardized mean difference has the important property that its value does not depend on the measurement scale. For example, consider a trial evaluating an intervention to increase birth weight. The mean birth weights in intervention and control groups were 2700 grams and 2600 grams with an average SD of 500 grams. The standardized mean difference will be:

$$(2700 - 2600)/500 = 0.2$$

If the trial had measured birth weight in ounces, the results would be means of 95 ounces and 92 ounces with an average standard deviation of 15 ounces. The standardized mean difference will be:

$$(95 - 92)/15 = 0.2$$

—the same number from the analysis based on grams.

So, if we have several trials assessing the same outcome, but using different scales, we use a standardized mean difference to convert all outcomes to a common scale, measured in units of standard deviations.

(Adapted from Higgins JPT, Green S [editors]. *Cochrane Handbook for Systematic Reviews of Interventions* Version 5.1.0 [updated March 2011]. The Cochrane Collaboration, 2011. Available from www.cochrane-handbook.org.)

†A useful statistic for quantifying inconsistency is

$$I^2 = \left(\frac{Q - df}{Q}\right) \times 100\%$$

where Q is the chi-squared statistic and df is its degrees of freedom. This describes the percentage of the variability in effect estimates that is due to heterogeneity rather than sampling error (chance).

(Adapted from Higgins JPT, Green S [editors]. *Cochrane Handbook for Systematic Reviews of Interventions* Version 5.1.0 [updated March 2011]. The Cochrane Collaboration, 2011. Available from www.cochrane-handbook.org.)

Self-Ligating Brackets

Self-ligating brackets have been around for decades,[12] but there has been a resurgence of interest over the past few years. Do the new self-ligating brackets truly offer advantages over conventional brackets? The literature is just starting to emerge in this area and is a good example of how early studies may be equivocal and provide challenges as a clinician seeks evidence for clinical decision making.

While conducting a search of the literature on self-ligation, it quickly becomes obvious that differences exist between in vitro and in vivo studies. However, there may be little correlation between those conducted in the lab and those on human subjects. For example, articles have been published for years in the *AJODO* based on in vitro adhesive shear/bond strength tests. However, a recent paper showed there was no relationship between the findings of in vitro and in vivo studies on adhesives.[13]

When several self-ligating brackets are mounted on a model with teeth (as in many in vitro studies) and a straight wire is pulled through them, the results show these brackets as having reduced friction. Clinicians naturally wonder whether this finding of low friction is, in fact, reflected in faster tooth movement and reduced treatment time. One of the more impressive three-dimensional instruments developed by Badawi et al.[14] serves as a laboratory-based human mouth model capable of measuring forces and moments applied by fixed orthodontic appliances. These bench-top systems cannot truly replicate a clinical environment, because alveolar bone and periodontial ligaments are difficult to simulate. Therefore, conclusions from these studies must be viewed with some caution. Nevertheless, the clinical questions to be answered are significant. Does self-ligation save chair time by being more efficient than brackets using elastomeric ligation? Are self-ligating appliances more hygienic than conventional appliances? Does self-ligation shorten overall treatment time? Do treatment outcomes with self-ligation systems produce different treatment outcomes compared with conventional appliances? Although we do not have enough high-level studies to make conclusive statements, answers to some of these questions are beginning to emerge as more investigations are submitted for publication.

In a study of treatment efficiency, Turnbull and Birnie[15] compared the efficiency of changing archwires in 131 consecutively treated patients. In each patient they measured the time it took to change archwires, comparing Damon2 brackets with a conventional twin bracket using Alastiks. The ligation of wires was twice as quick with the Damon2 bracket system, saving as much as 3 seconds per archwire change.

Regarding the issue of oral hygiene and plaque accumulation, Pandis et al. published an article titled, "Periodontal Condition of the Mandibular Anterior Dentition in patients with Conventional and Self-Ligating Brackets,"[16] which was a well-designed prospective cohort investigation. Fifty patients were assigned with the same treatment protocol, but one group had conventional brackets and the other self-ligating brackets (In-Ovation-R). Average follow-up time was 18 months when examined for plaque index, gingival index, calculus index, and probing depths for both cohorts. Under the conditions of this study, the self-ligating brackets did not have an advantage over conventional brackets with respect to the status of the periodontal tissues of mandibular anterior teeth.

Of course, the greatest interest in self-ligation has been whether it influences treatment time. The number of studies being completed on this topic is growing every day. Pandis et al.[17] investigated the time it took to align mandibular incisors, comparing self-ligating and conventional brackets on 54 patients treated in a prospective trial. All patients were randomly assigned from a common pool to receive either the Damon2 bracket or a conventional edgewise bracket, both with 0.022-inch bracket slots. All patients had an irregularity index of greater than 2 mm in the mandible and were treated without extraction. The conclusions noted that overall, there was no difference in the time required to correct mandibular crowding in either group. However, when moderate and severe crowding were examined separately, self-ligating brackets corrected the moderate crowding (<5 mm) 2.5 times faster than those with conventional appliances. This difference was insignificant for patients with the more severe crowding (>5 mm). There was an increase in proclination of mandibular incisors associated with correction of the crowding for both bracket groups.

Hamilton et al.[18] published a long-term in vivo study in the *Australian Orthodontic Journal* (2008) titled, "Comparison of Active Self-Ligating Brackets and Conventional Pre-adjusted Brackets." Their focus was to compare the efficiency of bracket systems as used by experienced clinicians in a specialty private practice setting. This study was a retrospective case analysis of 800 patients treated by an orthodontist with more than 20 years of orthodontic experience. Group 1 was composed of 400 consecutively treated patients with a conventional, preadjusted single wing orthodontic bracket (3M Unitek) with treatment starting in 1995. Group 2 was composed of 400 patients consecutively treated with active self-ligating brackets (InOvation) with treatment commencing in 2002 by the same practitioner. In the end, 762 patients were evaluated retrospectively—383 treated with conventional brackets and 379 with self-ligating brackets. The total treatment time, number of appointments, appointment intervals, breakage, and number of unscheduled appointments were recorded. That study group concluded that the self-ligating appliance offered no measurable advantage in treatment time. Those using both appliances spent comparable amounts of time in rectangular and round archwires. The number of debonded brackets and other emergency visits was significantly higher in patients treated with the self-ligating brackets.

Two more well-designed articles have recently been published in the *AJODO* that show little difference in the ability to align crowded teeth. Fleming et al.[19] completed a study to compare the effects of using a self-ligating bracket system (SmartClip) and a conventional edgewise bracket (Victory) to align incisors and improve transverse mandibular arch dimensional changes over a period of 30 weeks. A total of 66 patients were enrolled and randomly assigned to treatment groups. Over the period studied, bracket type had little effect on incisor inclination and positional changes, intercanine, and other arch dimensions. The authors concluded there was little difference overall in the pattern of arch alignment and leveling as related to the two appliance systems. In another study, Scott et al.[20] randomly assigned 62 subjects to investigate "Alignment efficiency of Damon3 self-ligating and conventional orthodontic bracket systems: a randomized clinical trial." The aim was to compare Damon3 brackets and Synthesis conventional bracket systems in the treatment of patients with 5 to 12 mm of lower incisor irregularity in a treatment protocol that included the extraction of first premolars. Their findings revealed that self-ligating brackets appeared to offer no measurable advantage in treatment time, number of visits, and time spent in initial alignment over the conventional bracket system used. In this study, Damon3 self-ligating brackets were no more efficient than conventional preadjusted brackets to achieve tooth alignment.

The evidence on self-ligating appliances will continue to accrue, but even with the existing literature, it may be difficult to draw conclusions because of conflicting reports. A systematic review on this topic offers the advantage of identifying and summarizing the best evidence with a specified and reproducible method, thereby facilitating conclusions regarding self-ligating brackets.[21] And as additional literature is published, systematic reviews can be updated, incorporating new studies if they meet inclusion criteria. It is important to understand that new evidence may alter our positions on issues such as self-ligation, especially when these reviews do not currently include large numbers of high-quality studies.

One- and Two-Phase Treatment for Class II Skeletal Problems

A considerable body of literature exists on the treatment of Class II malocclusions. Many studies have been conducted, including several randomized clinical trials, and numerous systematic reviews have addressed Class II therapy. Typical of the lasting impact that the Cochrane Library can have on a controversial subject is seen with the publication of a long-awaited systematic review of the efficiency of two-phase treatment to correct Class II malocclusions. The review is titled, "Orthodontic Treatment for Prominent Upper Front Teeth in Children."[22] The authors began their search of the literature by accessing every electronic database available and then followed with a hand search of key international orthodontic journals, with no restriction for language. To be included, studies had to be randomized or controlled clinical trials. The subjects were children or adolescents (aged 16 or younger) who received treatment to correct prominent maxillary front teeth. The interventions used included various fixed or removable appliances or headgear, with an untreated control group for comparison. Expected outcomes were (1) primary, the prominence of the maxillary front teeth and the relationship of the two jaws; and (2) secondary, self-esteem, any injury to these teeth, jaw joint problems, patient satisfaction, and the overall number of appointments required to complete treatment.

The search strategy yielded 185 titles and abstracts. From these, the authors obtained 105 full reports for further study. Eight trials were eventually included, with data from 592 patients who had Class II Division 1 malocclusion.[23–30] Three trials, with 432 participants, compared an early phase (phase I) of functional appliance treatment with an untreated control group. Significant differences were found in final overjet and ANB angle after phase I treatment.

Comparing the effect of headgear treatment with normal growth in an untreated control group showed a small but significant effect of headgear on overjet and a significant reduction in final ANB angle. However, no significant differences in overjet, ANB angle, or ANB change were found between patients treated with headgear and those treated with functional appliances.

Regarding treatment for adolescents, at the end of phase II treatment, the investigators found no significant differences in overjet, final ANB angle, or peer assessment rating (PAR) scores between children who had early treatment, with either headgear or functional appliances, and those who had not received early treatment. Similarly, there were no significant differences in overjet, final ANB angle, or PAR score between children who had received early treatment with headgear or a functional appliance. The evidence suggests that early orthodontic treatment for children with prominent maxillary front teeth is no more effective than one course of treatment when the child is in early adolescence.

What does this mean to the typical clinician when the next new patient scheduled for examination has a Class II malocclusion with moderate to severe skeletal disharmony? Clearly, this comprehensive review from the Cochrane Collaboration will help the clinician feel less pressure to begin early correction of this malocclusion, before 10 years of age. If the child's mandible has the genetic propensity to grow between 8 and 10 years, why not let it—and allow for the eruption of additional permanent teeth during this period of maturation? "But," you hasten to add, "aren't there many other reasons to start treatment as early as 8 years of age? What about arch–length problems, functional crossbites, the accidental fracture of a front tooth, or the opportunity to enhance a child's self-esteem?"

Yes, some of these problems are easier to treat early and should be addressed. For arch–length problems, the timely placement of a mandibular lingual arch can reduce problems by saving the e-space until all teeth have erupted. Large functional shifts, especially lateral shifts and those caused by posterior crossbites or interferences, are definitely valid reasons to begin treatment. Occlusal equilibration or expansion of the maxilla is effective at an early age to reduce the posterior crossbite. However, long-term stability of maxillary expansion beyond what might be expected as a result of normal growth, as claimed by Schiffman and Tuncay,[31] needs further study for confirmation. Children with crossbites might have reduced transverse growth potential, and long-term untreated controls are difficult, if not impossible, to find.

What about the effect of early treatment on the prevention of traumatic injuries to the prominent maxillary incisors in some Class II patients? It is still unclear just what treatment timing is most effective when evaluating the at-risk group in the long term. Nguyen et al.[32] found that children with an overjet greater than 3 mm have twice the risk for fracture as children whose overjet is smaller than 3 mm. In a study published by Artun et al.,[33] it was determined that the odds of maxillary incisor trauma before adolescence were 3.7 times higher in subjects with front teeth protruding more than 9.5 mm and 2.8 times higher in subjects with protrusion of 6.5 to 9.0 mm compared with children who had normal anterior dental relationships. This amounts to a 13% increase in risk for every 1 mm of increase in upper front tooth protrusion. This study confirmed prior reports that the risk of injury was about 2 times higher in boys than in girls and that most of these injuries involved trauma of the upper central incisors.

On the other hand, authors of long-term two-phase studies believe that for treatment to be effective in preventing trauma to incisors, it would have to start very early—shortly after the eruption of the central incisors.[34] Anything much later simply misses too many problems resulting from accidental trauma.

What about the opportunity to enhance self-esteem in young people as early as possible with an early phase of treatment? Short-term studies show varying degrees of improved well-being when children and adults receive orthodontic treatment.[35,] For a longer-term look, read the article by researchers from the University of Manchester in the United Kingdom.[36] The authors of this impressive study concluded that a lack of orthodontic treatment when there was a prior need did not lead to psychological difficulties in later life. Participants who needed orthodontic treatment as children and obtained it demonstrated better tooth alignment and greater satisfaction. However, when self-esteem at baseline was controlled for in this study from the United Kingdom, orthodontics had little positive impact on psychological health and quality of life in adulthood. While this is an excellent study, one must recognize that social psychological influences can carry different weights within varied populations or cultures.

These are definitely concerns that require input from patients and parents, and, for this very reason, they must always be considered as part of the evidence-based treatment decision.

When two phases of treatment are undertaken instead of one, there is a strong likelihood that more appointments will be necessary and the cost will be greater. For the majority of patients, it is not the most efficient way to correct a skeletal Class II problem. It may come down to our belief that we have little influence in predicting or altering growth of skeletal components of the face via orthodontic treatment. But we are probably better than ever at changing the dentoalveolar components of the malocclusions that we treat. Of course, many other forms of malocclusion can benefit from early treatment, but the ages of 10 to 13 are looking better all the time for starting Class II treatment.

ETHICAL CONSIDERATIONS FOR THE EVIDENCE-BASED PRACTICE

High ethical standards are one of the traits we most admire in professionals. A true professional understands that earning respect is a lifelong process, one that embraces moral principles that govern the character of an individual, an organization, or even a commercial entity. In the specialty of orthodontics, we aspire to remain competent, exude integrity, show respect for others, and put service above prestige or profit.

THE INDIVIDUAL PRACTITIONER

According to the American College of Dentists,[37] the study of ethics seeks the answers to two questions: "What should we do?" and "Why should we do it?" To answer these key questions for our specialty, we try to apply moral principles or virtues to the practice of orthodontics. We know that unethical conduct seriously compromises service to patients and undermines our collective ability to function as professionals. Traditional organizations such as the American Dental Association have enforced a code of ethics since 1866 and have experience on their side.

An emphasis on ethics and ethical conduct clearly distinguishes our standing as professionals. Without a solid ethical foundation, one simply cannot be a true professional. With the adoption of the dental practice acts by the states, we have been granted the privilege to practice. As long as high standards of professional conduct and practice are maintained, members of the specialty can expect to retain that privilege. Proper conduct, competence, professional development, dignified public relations, and concern for the reputation of the profession should be guiding principles for every orthodontist.

Any number of issues can seem to conflict with a person's effort to be an ethical practitioner. Advertising by an orthodontist can create problems in a community, leading to cries of unethical behavior. Although advertising is considered acceptable by most professional organizations, it must not (1) misrepresent fact, (2) mislead or deceive by partial disclosure of relative facts, (3) create false or unjustified expectations, (4) imply unusual circumstances, (5) misrepresent fees, (6) imply or guarantee atypical results, or (7) represent unique superiority over other practitioners regarding treatment outcomes—especially when the public cannot verify such claims.

Another potential problem is risk management. Risk management decisions are typically made from the doctor's perspective and for the doctor's benefit. Decision processes based on ethical principles always consider the patient's best interests, as well as the patient's values and preferences. Processes and decisions that do not include the patient's perspective might be good risk management but unethical.

THE PROFESSIONAL ASSOCIATION

Creative solutions designed to meet human needs for dental care in geographically isolated communities create an ethical challenge for organizations such as the American Dental Association and the American Association of Orthodontists. As professionals, we respect others and their need for basic dental care. And dentistry, because it is a profession, has special ethical interests in promoting access to care. The professional has an obligation to aid the community with its general problems and should be willing to donate some time for their solution. He or she should be willing to discuss, advise, guide, and aid in the oral health care of the community, in accordance with the rules established by organized dentistry. It seems obvious that a professional organization should be available to address potentially health-threatening dental conditions and to ease pain and suffering.

When conflicts arise, the choice between being legal and being ethical can be difficult. For any legal, legislative, or judicial resolution to a problem, one should ask, "Is the law a good one?" or "Was the court right?" Ethicists, on the other hand, argue that ethics, not law, establishes the ultimate standards for evaluating conduct. It is a professional obligation to work with colleagues to overturn unjust laws—that is, those who are in conflict with the best interests of patients and the public. However, the standard of care should be the same for all patients, regardless of the health care delivery system. Society should not use the services of underqualified providers to solve perceived access-to-care problems with a lower standard of care.

THE ORTHODONTIC MANUFACTURER/SUPPLIER

As the working relationship with an orthodontic manufacturer becomes more intertwined, the clinician has an obligation to represent professional qualifications accurately. A professional has a duty to avoid shaping the conclusions or perceptions of patients or other professionals by withholding or altering information that is needed for accurate assessment of a proposed treatment plan or type of appliance to be used. The clinician must disclose commercial relationships with companies when recommending products of those companies. An orthodontist can ethically have ties to commercial entities but should fully disclose these relationships to patients and professional colleagues when nondisclosure would lead to differing conclusions, perceptions, or misrepresentation. The "best interests" of our patients means that professional decisions by the orthodontist must consider patients' values and personal preferences. Patients must be informed of possible complications, alternative treatments, advantages and disadvantages of each, costs of each, and expected outcomes. Together, the risks, benefits, and burdens can be balanced. It is only after such consideration that the "best interests" of patients can be assured.

Manufacturers also have a responsibility to advertise responsibly by avoiding false or misleading statements. This is of particular importance when a commercial entity takes advertising directly to the public, effectively circumventing the advice of the attending orthodontist. A company that implies general superiority of one product over another without scientific proof, preferably published in peer-reviewed journals, is not behaving ethically and might be deceiving the very people who need care.

Core values represent a guide of ethical behavior for the orthodontist, the professional association, and the orthodontic manufacturer in this changing world. The American College of Dentists,[38] after years of study and reflection, compiled a description of values: the commitment to promoting oral health initiatives and protecting the public requires that the profession works together for the collective best interest of society. As such, an evidence-based approach assists orthodontists, professional associations, and manufacturers in relaying accurate information and guidance to the public.

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CHAPTER 30

Lasers in Orthodontics

Stephen Tracey, Antonio Gracco

OUTLINE

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Classification of Lasers
Lasers in Dentistry
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  Miscellaneous Tissue Removal
  Photostimulation of Aphthous and Herpetic Lesions
Summary

Orthodontic clinicians have long been challenged with soft tissue problems associated with orthodontic treatment. Uneven gingival margins make ideal bracket placement difficult, if not impossible. Short clinical crowns compromise the effectiveness of aligner treatment. Delayed eruption of teeth often results in an excessive number of appointments and extended treatment times. Aesthetically, compromised height-to-width ratios of anterior teeth and excess gingival display can turn an otherwise skillfully treated case into one that appears less than ideal. In the past decade, the introduction of lasers into the profession has allowed these problems to be addressed. This chapter will describe the use of lasers in orthodontics and discuss why they have become an indispensable tool in many orthodontic practices throughout the world.

HISTORICAL OVERVIEW

In 1917, Albert Einstein laid the foundation for the invention of the laser and its predecessor, "the maser," when he first theorized that photoelectric amplification could emit a single frequency, or stimulated emission. In 1953, Columbia University professor Charles Townes along with graduate students James Gordon and Herbert Zeigler produced the first microwave amplifier, or maser, that operated on principles similar to the laser but amplified microwaves rather than infrared or visible radiation. The term LASER is an acronym for Light Amplification by the Stimulated Emission of Radiation and was first introduced to the public in 1959 in a paper by Columbia University graduate student Gordon Gould. In 1960, American physicist Theodore Maiman at the Hughes Research Laboratories in Malibu, CA, built the first functioning laser.[1] Since that time, lasers have become nearly ubiquitous. They are in computer printers and DVD players; they record prices at the supermarket checkout; they guide weapons; and they measure distances between planets.

In 1962, dermatologist Dr. Leon Goldman introduced the laser to the medical profession when he became the first researcher to remove a tattoo with a ruby laser. Surgical uses for CO_2 lasers were investigated extensively from 1967 to 1970 by pioneers such as Dr. Thomas Polanyi and Dr. Geza Jako, and in the early 1970s, use of the CO_2 laser in ear, nose, and throat and gynecologic surgery became well established but was limited to academic and teaching hospitals. It was not until the early 1980s that the smaller but more powerful lasers began to make their way into community hospitals and physicians' offices.[2]

The first surgical laser developed specifically for dentistry, a 3-W Nd:YAG laser, was introduced in 1989, and in May 1997, the U.S. Food and Drug Administration

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approved the Er:YAG laser for use on dental hard tissues such as teeth and bones. Currently, there are more than 24 cleared indications for use of dental lasers in the United States.

SCIENTIFIC CONCEPTS

Light is a form of electromagnetic energy that can be thought of as both a particle and a wave. The elementary particle of light is called a photon and is typically described as a tiny packet of energy that travels in waves at the speed of light (186,282 miles per second in a vacuum). A *wave* of photons can be defined by two basic properties: amplitude and wavelength. *Amplitude* is the height of the wave from the zero axis to its peak. This correlates to the amount of energy for each photon, defined as the larger the amplitude, the greater is the energy, which is measured in joules. *Wavelength* is defined as the horizontal distance between any two corresponding points on the wave and is measured in meters, nanometers (10^{-9} meters) or microns (10^{-6} meters). As waves travel, they oscillate several times per second, termed *frequency*. Frequency is inversely proportional to wavelength: the shorter the wavelength, the higher the frequency.[3]

Ordinary light, such as that produced by an incandescent light bulb, is composed of many wavelengths of light and is unfocused or incoherent. The warm white glow seen by the human eye is the diffuse sum of many colors in the visible spectrum. Laser light is different from ordinary light in that it is monochromatic and consists of a single wavelength of light. In some cases, it is invisible to the human eye. Additionally, each wave of laser light is coherent, or identical in physical size, shape, and synchronicity. The monochromatic, coherent wave of light energy that is produced by a laser is a unique source of focused electromagnetic energy that is capable of usable work.

A laser is composed of three principal parts: an energy source, an active lasing medium, and two or more mirrors that form an optical cavity or resonator (Figure 30-1).

For amplification to occur, energy is supplied to the laser system by a pumping mechanism such as a flashlamp strobe device, an electrical current, or an electrical coil. This energy is pumped into an active medium contained within an optical resonator, producing a spontaneous emission of photons. Subsequently, amplification by stimulated emission takes place as the photons are reflected back and forth through the medium by the highly reflective surfaces of the optical resonator prior to their exit from the cavity via the output coupler. In the case of dental lasers, the laser light is delivered from the laser to the target tissue via a fiberoptic cable, hollow waveguide, or articulated arm. Focusing lenses, a cooling system, and other controls complete the system. The wavelength and other properties of the laser are determined primarily by the composition of the active medium, which can be a gas, a crystal, or a solid-state semiconductor (Figure 30-2).

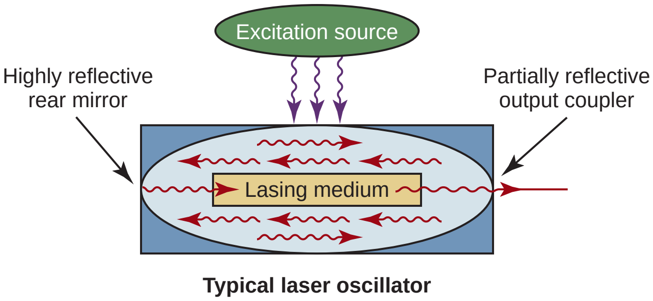

Excitation source
Highly reflective rear mirror
Partially reflective output coupler
Lasing medium
Typical laser oscillator

FIGURE 30-1 A laser is composed of three principal parts: an energy source, an active lasing medium, and two or more mirrors that form an optical cavity or resonator.

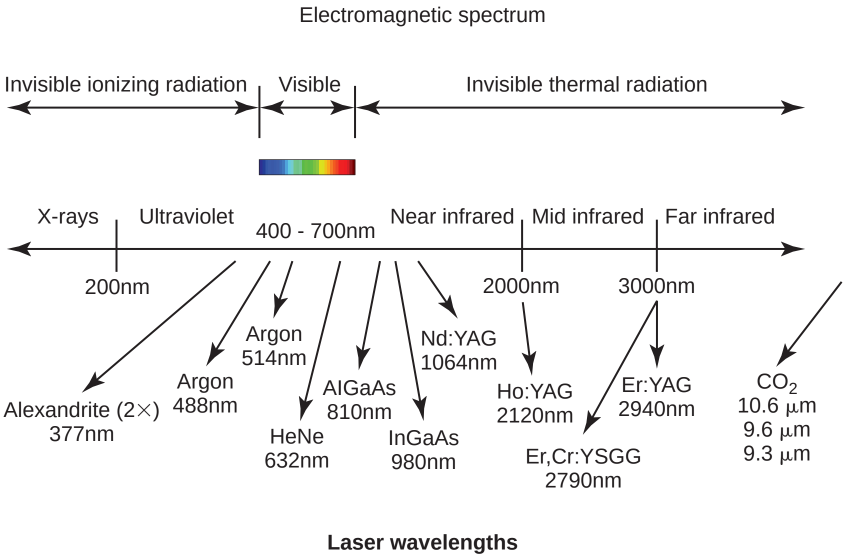


FIGURE 30-2 The wavelength of light produced by a dental laser is determined by the composition of its active medium, which can be a gas, a crystal, or a solid-state semiconductor.

CLASSIFICATION OF LASERS

It is generally recognized that lasers of all except the lowest powers can be potentially dangerous, particularly to human eyesight. Consequently, laser devices are classified according to their potential to cause biological damage. The pertinent parameters are laser output power, radiation wavelengths, exposure duration, and cross-sectional area of the laser beam at the point of interest.[4] Safety thresholds for lasers are expressed in terms of maximum permissible exposure (MPE). As established by the International Electrotechnical Commission (IEC), the classifications are as follows:

Class 1. A Class 1 laser is safe for use under all reasonably anticipated conditions of use; in other words, it is not expected that the MPE can be exceeded. This class may include lasers of a higher class whose beams are confined within a suitable enclosure so that access to laser radiation is physically prevented.

Class 1M. These lasers produce large-diameter beams, or beams that are divergent. The MPE for a Class 1M laser cannot normally be exceeded unless focusing or imaging optics are used to narrow down the beam. If the beam is refocused, the hazard of Class 1M lasers may be increased and the product class may be changed.

Class 2. A Class 2 laser emits in the visible region. It is presumed that the human blink reflex will be sufficient to prevent damaging exposure, although prolonged viewing may be dangerous.

Class 2M. A Class 2M laser emits in the visible region in the form of a large diameter or divergent beam. It is presumed that the human blink reflex will be sufficient to prevent damaging exposure, but if the beam is focused down, damaging levels of radiation may be reached and may lead to a reclassification of the laser.

Class 3R. A Class 3R laser is a continuous wave laser that may produce up to five times the emission limit for Class 1 or Class 2 lasers. Although the MPE can be exceeded, the risk of injury is low. The laser can produce no more than 5 mW in the visible region.

Class 3B. A Class 3B laser produces light of an intensity such that the MPE for eye exposure may be exceeded and direct viewing of the beam is potentially serious. Diffuse radiation (i.e., that which is scattered from a diffusing surface) should not be hazardous. CW emission from such lasers at wavelengths above 315 nm must not exceed 0.5 W.

Class 4. Class 4 lasers are of high power (typically up to 500 mW or more if CW, or 10 J • cm^{-2} if pulsed). These are hazardous to view at all times, may cause devastating and permanent eye damage, may have sufficient energy to ignite materials, and may cause significant skin damage. Exposure of the eye or skin to both the direct laser beam and to scattered beams, even those produced by reflection from diffusing surfaces, must be avoided at all times. In addition, they may pose a fire risk and may generate hazardous fumes. Nearly all medical and dental lasers fall into this category.

LASERS IN DENTISTRY

Since the development of the first laser by Maiman in 1960, dental interest in lasers has been high and research has continued to improve dental treatment through laser application.[1] Argon curing lasers have been available since the 1980s, diagnostic lasers have been used since the late 1990s to assist in detecting caries, and three-dimensional laser scanners have been used for many years to translate physical plaster models into virtual e-models (Figure 30-3).

In this chapter, we will be focusing on the surgical applications of dental lasers involving hard and soft tissues.

Laser Effects on Tissue

The light energy produced by a laser can have four different interactions with a target tissue[5,6] (Figure 30-4).

The first is reflection, which involves redirection of the beam off the surface of the tissue, with no effect on the target tissue. The second effect is transmission of the laser energy directly through the tissue, again with no effect on the target tissue. The third effect is a scattering of the laser energy, resulting in a weakening of the intended energy and possible undesirable transfer of heat to adjacent nontarget tissue. The fourth effect is absorption of the laser energy by the target tissue. In reality, there is always a mixture of all four interactions taking place simultaneously any time laser energy is directed at a target tissue, but ultimately it is the interaction of absorption that is of primary interest. When laser light is absorbed, the temperature of the target tissue is elevated resulting in a number of photothermal effects based upon the water content of the tissue. When a temperature of 100°C is reached, vaporization of the water within the tissue occurs, a process called *ablation.* Because soft tissue is composed of a very high percentage of water, excision of soft tissue commences at this temperature. At temperatures below 100°C but above approximately 60°C, proteins begin to denature without vaporization of the underlying tissue. Conversely, at temperatures above 200°C, tissue is dehydrated and then burned, resulting in an undesirable effect called *carbonization.*

Absorption requires an absorber of light, termed *chromophores,* which have a certain affinity for specific wavelengths of light: the higher the affinity, the greater is the absorption of energy. The primary chromophores in intraoral soft tissue are melanin, hemoglobin, and

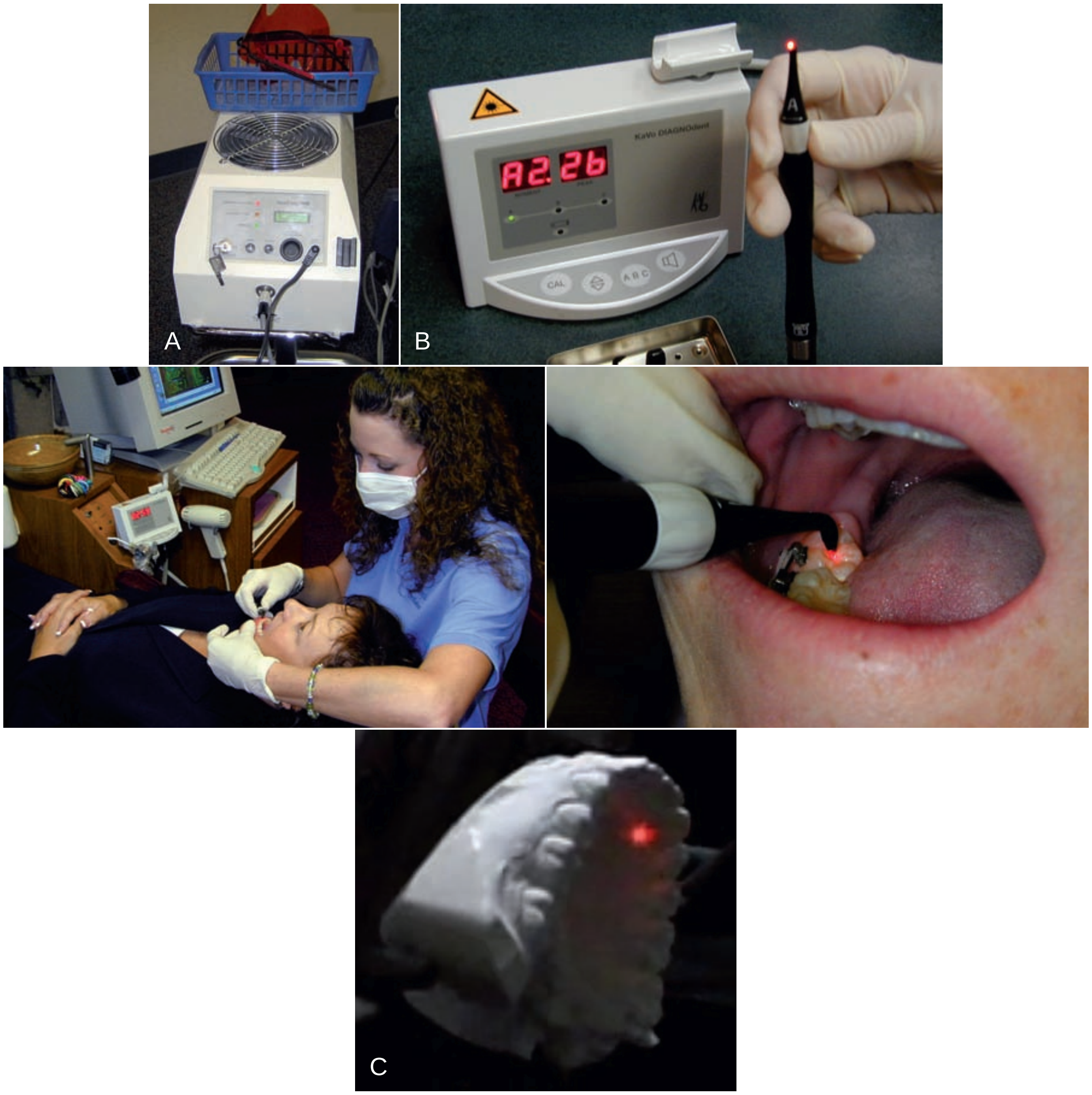


FIGURE 30-3 Examples of nonsurgical lasers used in dentistry. **A,** Argon curing laser. **B,** Caries detection laser. **C,** Three-dimensional laser scanner.

water, and in dental hard tissues, water and hydroxyapatite. Different laser wavelengths have different absorption coefficients with respect to these primary tissue components, making laser selection procedure dependent[7–9] (Figure 30-5).

Dental Surgical Lasers

Because of the varied composition of dental tissue and the differing ways that laser energy is absorbed, there is no one perfect dental laser[10]. There are many laser systems available today,[11–20,21–22] each with its own set of benefits and drawbacks. The most common lasers used in dentistry today are the CO_2 laser, the Nd:YAG laser, the erbium lasers (Er:YAG and Er,Cr:YSGG), and the diode laser, each generically named for the active medium contained within the device.[23–26]

CO_2 Laser. The CO_2 laser was one of the earliest lasers used in general medical surgeries, first appearing in the early 1970s. It has an active medium of carbon dioxide gas and typically produces an invisible laser wavelength of approximately 10,600 nm (10.6 microns), in the mid-infrared portion of the electromagnetic spectrum. Because the relatively long wavelength cannot be transmitted through optical fiber, it is delivered from the laser to the target tissue via a hollow waveguide (a flexible hollow tube with a highly reflective inner surface) or articulated arm (a series of tubes articulated with reflective mirrors) combined with a hollow steel or solid ceramic tip. The laser energy is focused onto the tissue by the tip in a noncontact mode. The CO_2 wavelength has a very high affinity for water, resulting in rapid soft tissue removal and hemostasis with a very shallow depth of penetration. Although it possesses the highest[27] absorbance of any

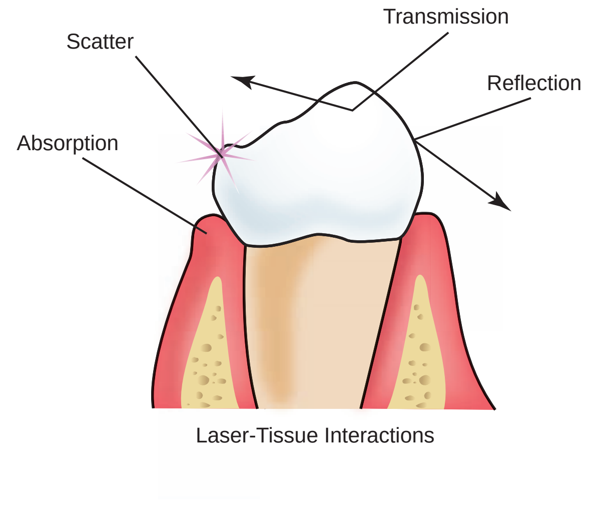
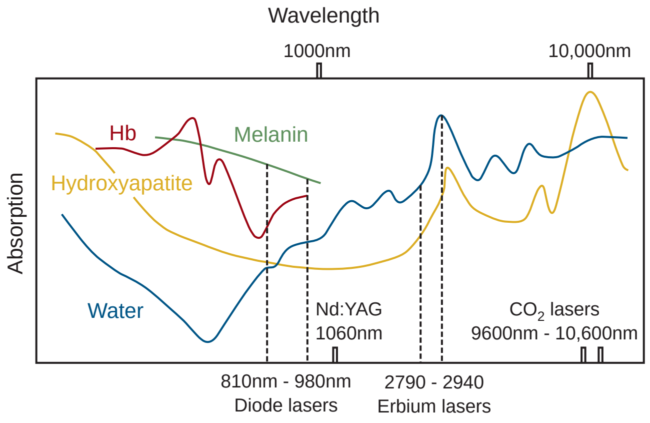


FIGURE 30-4 Laser energy can have four different interactions with a target tissue: reflection, transmission, scatter, and absorption. In reality, all interactions are taking place simultaneously, but the interaction we are most interested in is absorption.



Absorption of various tissue chromophores by wavelength

FIGURE 30-5 The primary chromophores of intraoral tissue that absorb laser energy are pigment (melanin), hemoglobin, hydroxyapatite, and water. Soft tissue lasers produce energy that is absorbed primarily by melanin and hemoglobin, while hard tissue lasers produce energy that is absorbed primarily by hydroxyapatite and water.

laser in hydroxyapatite, current technology limits its hard tissue applications. Practitioners must exercise caution when performing soft tissue surgery in close proximity to tooth structure because of the potentially destructive interaction. Additional disadvantages of the CO$_2$ laser are its relative large size and high cost.

Nd:YAG Laser. The Nd:YAG laser was the first laser designed specifically for dentistry. Its solid active medium is a crystal of yttrium aluminum garnet doped with neodymium, producing a wavelength of approximately 1064 nm, in the invisible near-infrared portion of the electromagnetic spectrum. Laser energy is delivered from the laser to the target tissue by a fiberoptic, most often with the fiber tip in light contact with the tissue. The Nd:YAG wavelength is highly absorbed by pigmented tissue, making it a very effective surgical laser for cutting and coagulating dental soft tissues with good hemostasis. Because it is only slightly absorbed by dental hard tissues, with little interaction with sound tooth structure, soft tissue surgery adjacent to teeth is performed safely and precisely. In addition to its surgical applications,[28] there has been research into using the Nd:YAG laser for nonsurgical sulcular debridement in periodontal disease control.[29–31] Although much of the literature[32,33] suggests there is little evidence to support the superiority of it over traditional modalities of periodontal therapy, one recent study[34] evaluating the Laser Assisted New Attachment Procedure (LANAP) demonstrated cementum-mediated new connective tissue attachment and apparent periodontal regeneration of diseased root surfaces in humans.

Erbium Lasers. Within the erbium "family" of lasers, there are two distinct wavelengths that have indications for both hard and soft tissue procedures. The active medium of the Er,Cr:YSGG laser is a solid crystal of yttrium scandium gallium garnet that is doped with both erbium and chromium, producing a wavelength of approximately 2790 nm. The Er:YAG laser has an active medium of yttrium aluminum garnet that is doped with erbium, producing a wavelength of approximately 2940 nm. Both wavelengths are near the boundary of the near- to mid-infrared portion of the electromagnetic spectrum and emitted in a free-running pulsed mode. Currently, Er,Cr:YSGG lasers deliver energy to target tissue through a handpiece via a fiber, whereas Er:YAG lasers use a handpiece in conjunction with either a hollow waveguide, an articulated arm, or a fiberoptic bundle. The erbium wavelengths have a high affinity for hydroxyapatite and the highest absorption in water of any dental laser wavelengths. Consequently, an erbium-based laser would be the laser of choice for treatment of dental hard tissues.[35] Water, which is present in all dental tissues in varying amounts, absorbs the erbium wavelengths extremely well. In enamel, absorption causes vaporization of the water contained within the mineral substrate and massive volume expansion. This expansion results in a micro-explosion in the tooth with surrounding material literally being blown away. Due to the very low penetration depth of the erbium wavelength and the fact that most of its energy is absorbed by water, very little heat is transferred to adjacent tissue with minimal effect on the pulp. In addition to hard tissue procedures, erbium lasers can also be used for soft tissue ablation because dental soft tissue also contains a high percentage of water.[36] However, hemostasis is not as pronounced as would be seen with diode laser ablation, and care must be taken when performing soft tissue procedures adjacent to teeth.

Diode Laser. The active medium of the diode laser is a solid state semiconductor made of aluminum, gallium, arsenide, and occasionally indium, that produces laser wavelengths ranging from approximately 810 nm to 980 nm. These wavelengths fall at the beginning of the near-infrared electromagnetic spectrum and are invisible to the human eye. Diode lasers deliver laser energy from the laser to the working area by a fiberoptic cable or disposable fiberoptic tip, in light contact with the target tissue for ablating procedures. All diode wavelengths are absorbed primarily by tissue pigment (melanin) and hemoglobin. Conversely, they are poorly absorbed by the hydroxyapatite and water present in enamel. Consequently diode lasers are excellent soft tissue surgical lasers and indicated for incising, excising, and coagulating gingiva and mucosa. Specific procedures include aesthetic gingival recontouring, soft tissue crown lengthening, exposure of soft tissue impacted teeth, removal of inflamed and hypertrophic tissue, frenectomies, and photostimulation of apthous and herpetic lesions.[37] Because diode laser wavelengths are poorly absorbed by tooth structure and metal,[38] soft tissue surgery can safely be performed in close proximity to enamel, orthodontic appliances, and temporary anchorage devices.

SURGICAL LASERS IN ORTHODONTICS

Laser Selection

No single laser wavelength can be used to optimally treat all dental diseases. However, the needs of the orthodontic clinician are unique and selection of the most appropriate laser for orthodontic applications is ideally determined by examining four important factors: procedure specificity, ease of operation, portability, and cost. CO_2 and Nd:YAG are not ideally suited for orthodontic applications and are hampered by their large size and high cost. Erbium lasers are extremely popular in dentistry today and hold the singular distinction of being able to perform both hard and soft tissue procedures.[39,40] However, it is the diode laser that seems most ideal for incorporation into the orthodontic specialty practice. With regard to procedure specificity, the diode laser's sole purpose is soft tissue surgery. It safely removes tissue without risk to adjacent tooth structure and provides excellent hemostasis.[41] When used to perform soft tissue procedures, erbium lasers require careful attention to avoid unintended damage to enamel and dentin and produce inferior hemostasis.[42] As to ease of operation, most practitioners prefer the diode laser's dry-field operation and the proprioceptive feedback provided by the light contact of the fiber tip with target tissue during ablation. In contrast, erbium lasers are typically operated in a noncontact mode along with a cooling water spray. Regarding portability, being able to easily move a laser from chair to chair or even office to office is an especially important feature to consider when selecting a laser for the typical orthodontic practice. Even the largest diode laser is dwarfed in comparison to the typical erbium laser, which occupies a much greater footprint and weighs as much as 75 pounds (Figure 30-6, *A*). In contrast, the smallest diode laser is similar in size to an electric toothbrush and weighs in at a scant 1.9 ounces (Figure 30-6, *B*). The cost of an erbium laser is in the vicinity of $80,000, whereas a quality diode laser can be obtained for well under $10,000. With this in mind, most orthodontic clinicians interested in purchasing a dental laser would be best served with the selection of a diode laser due to its soft tissue specificity, simple operation, small size, and relatively low cost[43,44] (Figure 30-6, *C*).

Laser Safety

While most dental lasers are relatively simple to use, certain precautions should be taken to ensure their safe and effective operation.[4] First and foremost is protective eyewear by anyone in the vicinity of the laser while it is in use. This includes the doctor, chairside assistants, patient, and any observers such as family or friends (Figure 30-7, *A*). It is critical that all protective eyewear worn is wavelength specific (Figure 30-7, *B*). Most surgical lasers produce a wavelength of light that is outside the visible portion of the electromagnetic spectrum. Consequently, sunglasses or safety glasses designed for use with visible dental curing lights are ineffective to protect the eye from potentially irreversible damage as a result of exposure to dental laser light. Additionally, accidental exposure to nontarget tissue can be prevented through the use of warning signs posted outside the nominal hazard zone (Figure 30-7, C), limiting access to the surgical environment, minimizing reflective surfaces, and ensuring the laser is in good working order with all manufacturer safeguards in place. With regard to prevention of possible exposure to infectious pathogens, high volume suction should be used to evacuate any vapor plume created during tissue ablation, and normal infection protocols should be followed. Each office should have a designated Laser Safety Officer to supervise the proper use of the laser, coordinate staff training, oversee the use of protective eyewear, and be familiar with pertinent regulations.

Diode Laser Setup and Troubleshooting

As stated previously, the diode soft tissue laser is the dental laser most ideally suited for orthodontic applications. Consequently, the remainder of this chapter will deal exclusively with its setup and use.

Fiber Preparation. The diode laser transmits laser light from the laser to the target tissue via a fiberoptic cable or disposable fiberoptic tip. In the case of a fiberoptic cable, a 400-micron optical fiber is recommended, because smaller-diameter fibers tend to be more friable and breakable. Prior to use, a sufficient portion of protective outer cladding must be removed with an appropriately sized stripping device in order to expose the inner

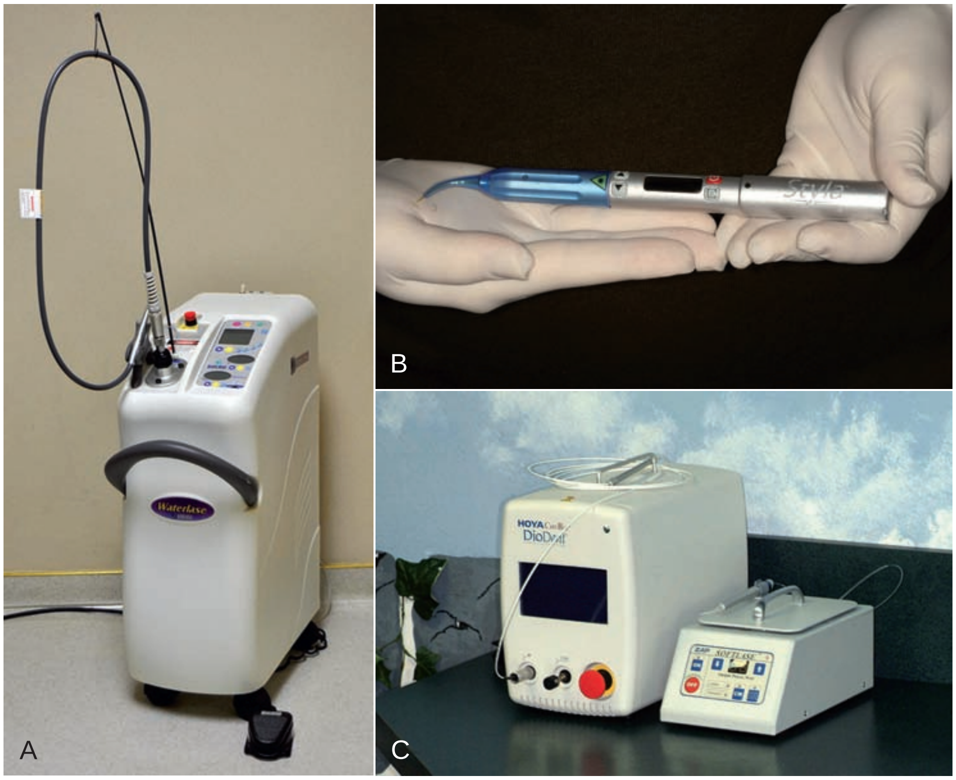


FIGURE 30-6 Selection of the most appropriate laser for orthodontic applications is determined by procedure specificity, ease of operation, portability, and cost. **A,** Erbium lasers are very popular dental lasers due to fact that they are the only lasers that can perform both hard and soft tissue procedures. **B,** The smallest diode laser weighs only 1.9 oz and can be held in the palm of your hand. **C,** Diode lasers are more appropriate for orthodontic applications due to the fact that they perform only soft tissue procedures and are simpler to operate, much smaller, and significantly less expensive than any other dental laser.

glass fiber[45] (Figure 30-8, *A*). The amount of outer cladding removed is determined by the length of the handpiece supplied with the laser, such that any exposed fiber is completely contained within the handpiece (Figure 30-8, *B*). Before each patient use, 2 to 3 mm is cut off the end of fiber to avoid cross-contamination. Normally, a small cleaving stone is used to nick the fiber before it is broken off, with care being taken to create a clean cut so that the light source is focused rather than dispersed (Figure 30-8, *C*). Alternately, a ceramic scissors can be used to cleave the fiber (Figure 30-8, *D*). Once the cleaved fiber has been inserted into the handpiece (Figure 30-8, *E*), a disposable plastic tip is fitted over the fiber tip and placed on the end of the handpiece, leaving approximately 3 mm of fiber exposed (Figure 30-8, *F*). The fiber tip is then "initiated" by placing some form of pigment on the end of the fiber in order to create a hyperfocus of usable laser energy at the tip. One of the most effective ways to deposit pigment on the tip is to lightly tap the end of the fiber onto a sheet of articulating film while the laser is activated (Figure 30-8, *G*). In the case of a disposable fiberoptic tip, it is not necessary to strip or cleave the fiber, although tip initiation is still required (Figure 30-8, *H*).

Basic Power Settings. To prevent collateral thermal damage to adjacent tissue, the Academy of Laser Dentistry recommends using the least amount of power that can effectively accomplish a desired procedure[46]. For most soft tissue ablation procedures, a setting of 1 to 1.2 W will result in excellent tissue removal with minimal thermal degeneration of adjacent tissue. Areas where soft tissue tends to be somewhat denser, such as the palate and the fibrous tissue distal to the lower second molars, may require settings closer to 1.4 W, whereas frenectomy procedures often require settings as high as 1.6 W. In addition to adjusting the amount of power required to safely and effectively ablate various soft tissues, it is also necessary to choose between operating the laser in either continuous-wave mode or pulsed-wave mode (Figure 30-9).

Although some practitioners have advocated using pulsed-wave mode to potentially reduce patient discomfort and minimize adjacent tissue damage, in actual practice there seems to be little benefit to this strategy when ablating tissue with a diode laser. In contrast to the free-running pulsed/high-peaked power light produced by Nd:YAG and erbium lasers, diode lasers produce a continuous wave of laser light that can only be "pulsed"

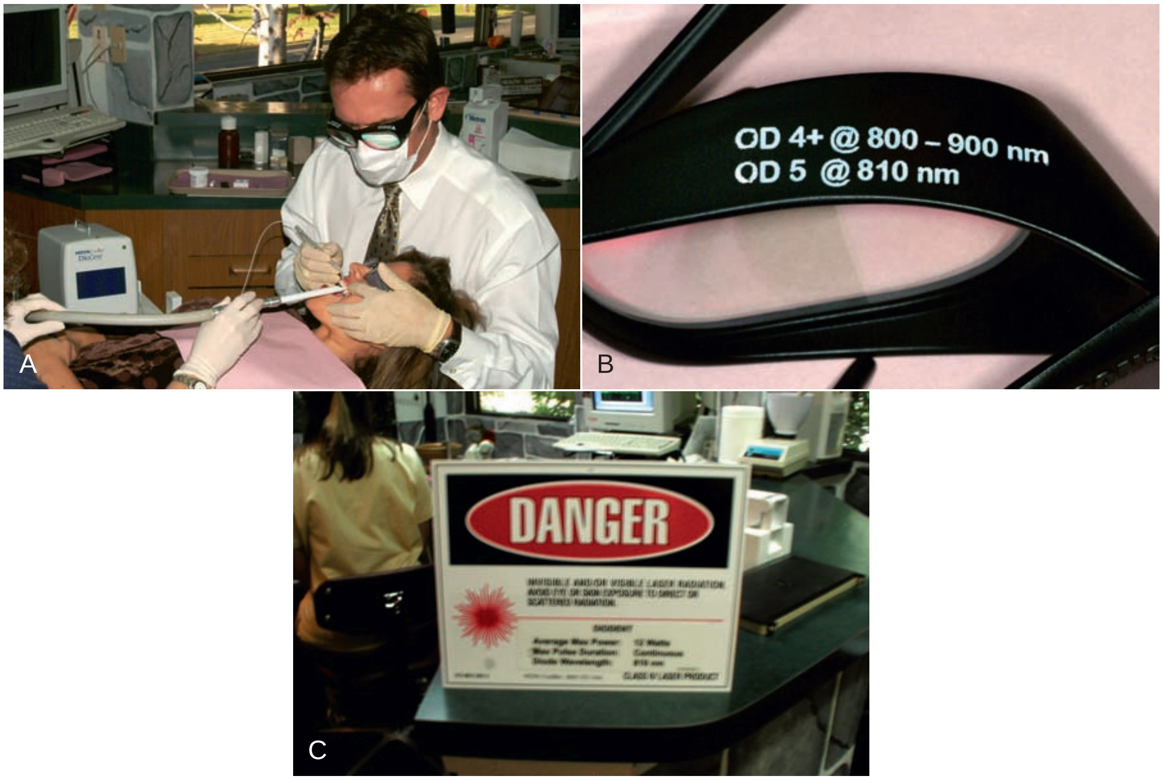


FIGURE 30-7 When operating a dental laser, safety is first and foremost. **A,** Anyone in the vicinity of the laser should use protective eyewear and high volume suction should be used to evacuate vapor plume. **B,** Protective eyewear should be wavelength specific. **C,** Accidental exposure to laser light can be prevented through the use of warning signs and limiting access to the surgical environment.

through the use of a mechanical gate that opens and closes to disrupt the flow of light, much like passing light through the turning blades of a fan. Consequently, when a diode laser is operated in pulsed mode, the power produced per unit of time (i.e., watts) is for all practical purposes cut in half, rendering the laser ineffective unless power settings are doubled. Additionally, the compounded topical anesthetic used for most laser procedures works so well that patients rarely experience pain during the procedure, and there is no more thermal damage seen using continuous-wave mode than with pulsed-wave mode. Therefore, it is generally recommended that a diode laser be operated in continuous-wave mode for most ablation procedures.

Laser Troubleshooting. Diode lasers use a solid-state semiconductor power source and have few moving parts. As a result, they have proved to be remarkably reliable and virtually trouble free. On occasion, practitioners will encounter cases when tissue ablation seems deficient, despite adequate power settings. To pinpoint the problem, first ensure that all power switches and key locks have been placed in the "on" position (Figure 30-10, *A*). Virtually all surgical lasers have multiple power switches and safety locks to prevent accidental activation and will operate correctly only if all have been switched on. To confirm that the fiberoptic tip has been initiated properly, see Figure 30-10, *B*. An uninitiated tip will fail to focus enough energy at the end of the fiber to adequately ablate tissue. Next check to see if the fiberoptic cable has been inadvertently fractured. Poor fiber management can result in a hidden break anywhere along the length of the fiber if it is stepped on or rolled over with a chair (Figure 30-10, *C*). And fourth, if the laser is being operated in pulsed-wave mode for any reason, be sure that power settings normally used in continuous-wave mode have been doubled to compensate for the reduction in power per unit of time (Figure 30-10, *D*).

Periodontal Considerations

It is important to note that when the diode laser is used judiciously, it is a safe and effective tool in the hands of a properly trained orthodontic practitioner. Violation of basic periodontal principles can result in less than desirable results. Respect for maintenance of biologic width is important. Typically biological width is measured from the free gingival margin to the crestal bone and is approximately 3 mm, consisting of 1 mm of junctional epithelium and 1 mm of connective tissue attachment combined with a gingival sulcus of approximately 1 mm (Figure 30-11).

Should this biological width be violated with excessive removal of gingival tissue along with placement of

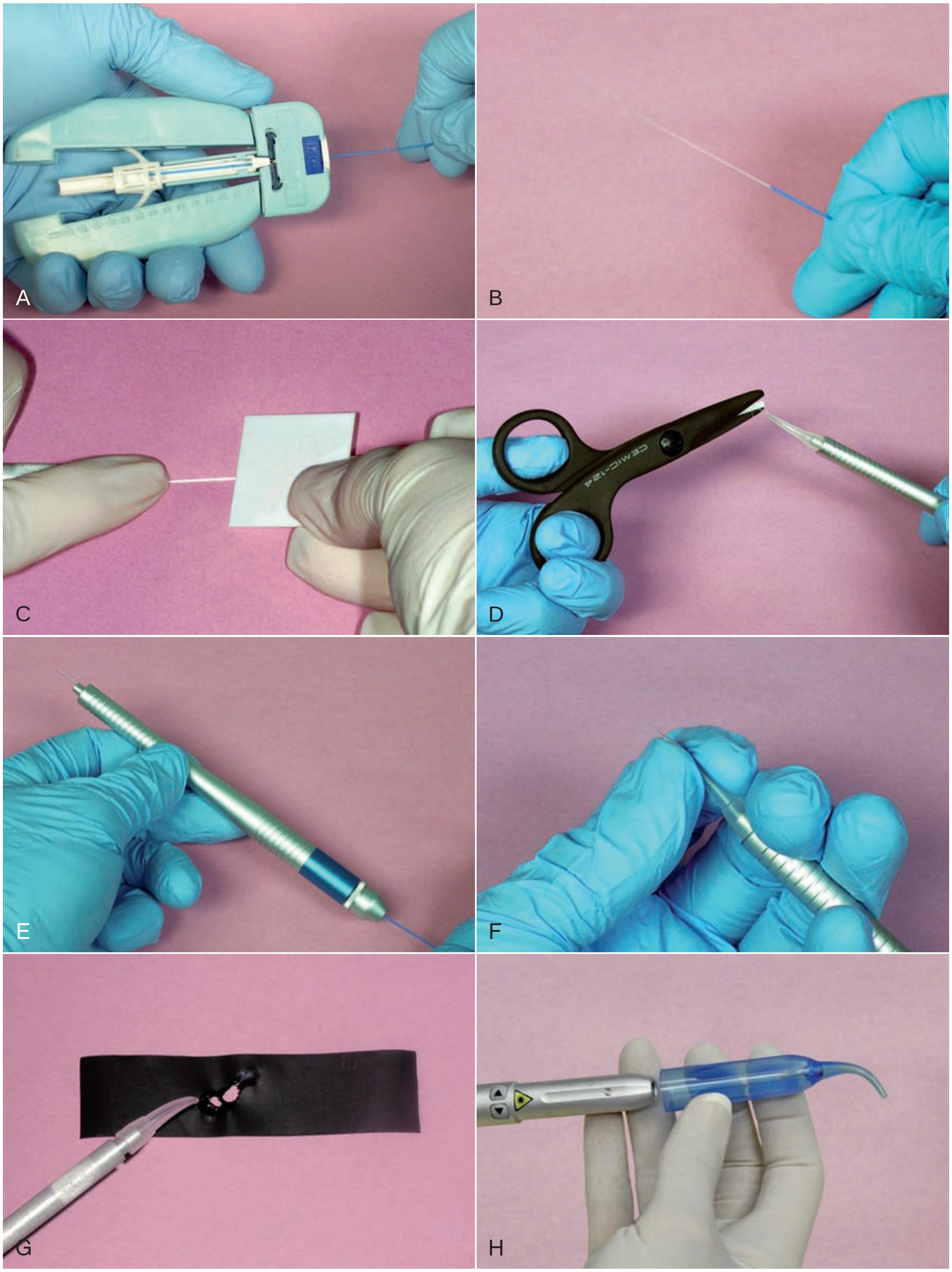
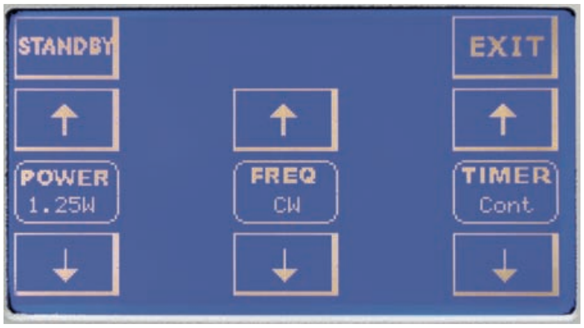


FIGURE 30-8 The diode laser transmits light from the laser to the target tissue via a properly prepared fiberoptic cable or disposable fiberoptic tip. **A,** Protective outer cladding is removed with a stripping device. **B,** The amount of outer cladding removed is determined by the length of the laser handpiece. **C,** Prior to each patient, 2 to 3 mm of fiber is removed using a cleaving stone. **D,** The fiber can also be cleaved using a ceramic scissors. **E,** The fiber is inserted into the handpiece. **F,** A disposable plastic tip is placed onto the handpiece, leaving approximately 3 mm of fiber exposed. **G,** The tip is initiated by lightly tapping the end of the fiber onto a sheet of articulating film while the laser is activated. **H,** In the case of a disposable fiberoptic tip, it is not necessary to strip or cleave the fiber; however, tip initiation is still required.



POWER 1.25W
FREQ CW
TIMER Cont

FIGURE 30-9 For most soft tissue ablation procedures, a power setting of approximately 1.2 W in continuous wave mode will result in excellent tissue removal with minimal thermal degeneration of adjacent tissue.

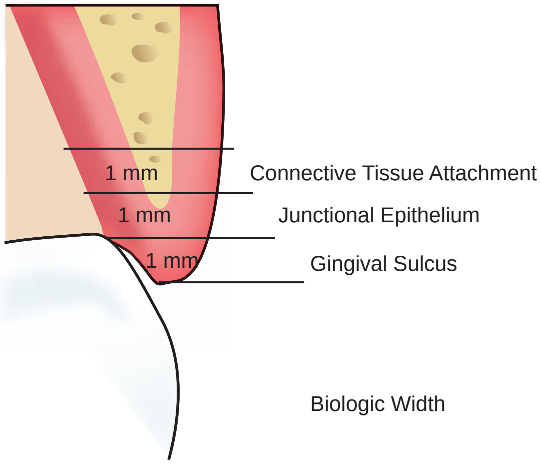


FIGURE 30-11 If biological width is violated with excessive removal of gingival tissue, deleterious consequences may result. If a restoration is placed within this zone, possible ramifications include chronic gingival inflammation and unpredictable bone loss. In the absence of an encroaching restoration, excised gingival may grow back in order for biological width to return to its normalized state.

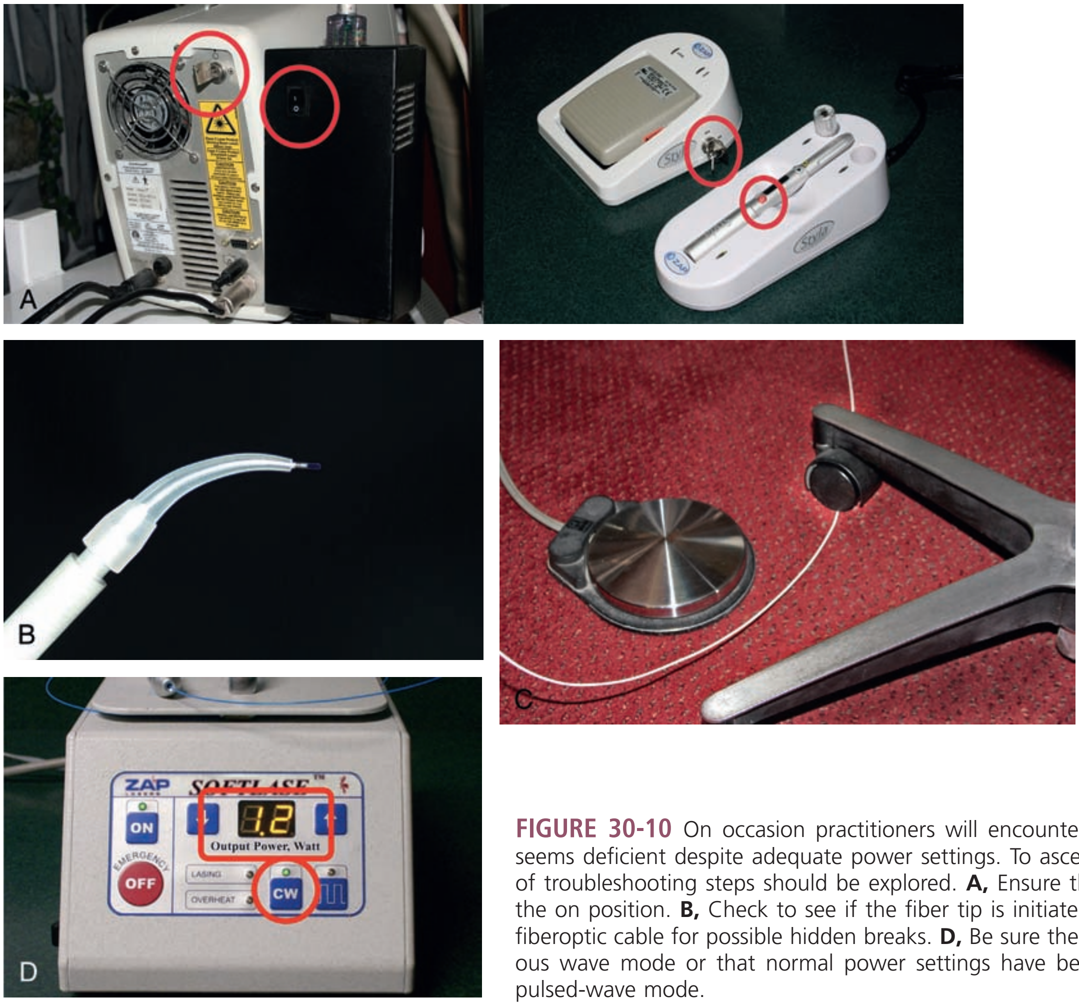


FIGURE 30-10 On occasion practitioners will encounter cases when tissue ablation seems deficient despite adequate power settings. To ascertain the problem, a number of troubleshooting steps should be explored. **A,** Ensure that all power switches are in the on position. **B,** Check to see if the fiber tip is initiated sufficiently. **C,** Examine the fiberoptic cable for possible hidden breaks. **D,** Be sure the laser is operating in continuous wave mode or that normal power settings have been doubled for operation in pulsed-wave mode.

a restoration within that zone, deleterious consequences may result including chronic inflammation of the gingiva and unpredictable bone loss. Fortunately, few, if any, orthodontic laser procedures involve placement of restorations after tissue removal. However, both doctor and patient must be aware that in some cases, excised marginal tissue may grow back as biological width returns to its natural state. With this in mind, cases requiring a significant amount of tissue removal are best referred to a surgical specialist such as a periodontist or oral surgeon for surgical crown lengthening. Another contraindication for soft tissue removal with the laser is exposure of unerupted teeth in unattached, nonkeratinized gingiva because this may result in a loss of attached gingiva once the tooth is brought into the arch form.

Medicolegal Considerations

Conservative soft tissue surgery with a dental laser is considered within the scope of accepted orthodontic treatment and typically considered a covered procedure under most professional liability insurance policies designed for orthodontic specialists. Each clinician should check with his or her insurance carrier to determine if soft tissue laser procedures are covered by the specific policy. Informed consent should be routine and is best handled as part of the general consent form that all patients read and sign prior to the initiation of orthodontic treatment. Although hands-on training and proficiency certification are not required to operate a dental laser in most states, it is highly recommended that each clinician take a course from a reputable provider. The Academy of Laser Dentistry (www.laserdentistry.org) is an excellent source for information and training pertaining to all dental lasers.

Surgical Procedure

In most cases, adequate soft tissue anesthesia required for laser-assisted tissue removal is obtained via application of a compounded topical anesthetic gel such as TAC 20% (lidocaine 20%, tetracaine 4%, and phenylephrine 2%) or Profound PET (prilocaine 10%, lidocaine 10%, tetracaine 4% and phenylephrine 2%).[47–49] The combination of the various local anesthetics along with the vasoconstrictor phenylephrine produces profound anesthesia in a relatively short amount of time.[29,50,51] After the target tissue is dried, topical anesthetic gel is applied to the area with a cotton-tipped applicator or cotton roll and left in place for approximately 3 to 4 minutes (Figure 30-12, *A*). Be advised that if the gel is inadvertently left on the tissue longer, mild tissue sloughing may occur as a result of the vasoconstrictive properties of the phenylephrine. Occasionally, in areas of thicker, denser tissue as seen on the palate and on the distal of an erupting lower second molar, topical anesthesia alone is insufficient and injection of local anesthetic solution is required.

Once the target tissue has been sufficiently anesthetized, a periodontal probe is used to measure sulcus depth and biological width on the teeth to be recontoured in order to determine how much tissue can be safely removed (Figure 30-12, *B*). If desired, these measurements can be used to outline the proposed line of tissue removal with puncture marks made with the periodontal probe (Figure 30-12, *C*).

The operator activates the laser with a foot pedal and gently moves the tip of the fiber across the target tissue in a light contact mode. Tissue is removed with an action similar to brush strokes, “painting away” the desired amount with the fiber tip held at various angles to provide ideal tissue contours and a beveled gingival margin rather than an abrupt ledge (Figure 30-12, *D*). Careful attention must be paid to the interaction of the laser energy with the target tissue. Leaving the fiber tip in one spot too long will result in carbonization and unnecessary collateral damage, whereas moving the tip too quickly will result in an insufficient absorption of energy to produce ablation. As stated previously, it is imperative that an assistant hold a high-volume aspirator at the site of ablation in order to evacuate vapor plume and objectionable odors. On occasion, ablated tissue will begin to build up on the end of the fiber tip. This should be removed by an assistant with a 2 × 2 gauze pad moistened with water. Once satisfactory tissue removal has been achieved, any remnants of slightly carbonized tissue remaining, termed the “char layer,” are removed with light pressure using a micro-applicator brush or cotton-tipped applicator soaked in 3% hydrogen peroxide solution (Figure 30-12, *E*).

Although no special postoperative care is required,[52] patients are advised to keep the area clean and plaque free with gentle brushing and to avoid foods and liquids that may cause pain or irritation to the tissue while it is healing. In cases involving more extensive tissue removal or significant beveling, over-the-counter analgesics are recommended.

CLINICAL APPLICATIONS

Aesthetic Gingival Recontouring

Gingival aesthetics play a large role in the visual assessment of a finished orthodontic case. Excessive gingival display, uneven gingival contours, and disproportionality of crown heights and widths as a result of less than ideal gingival anatomy significantly diminish the aesthetic value of even the most perfectly aligned teeth. In the past, only the most severe gingival discrepancies were referred out after orthodontic treatment due to the high cost and pain associated with traditional gingivectomy procedures. Now, with the advent of the diode laser many clinicians are choosing to include optimization of gingival aesthetics as part of comprehensive orthodontic treatment.[53–61]

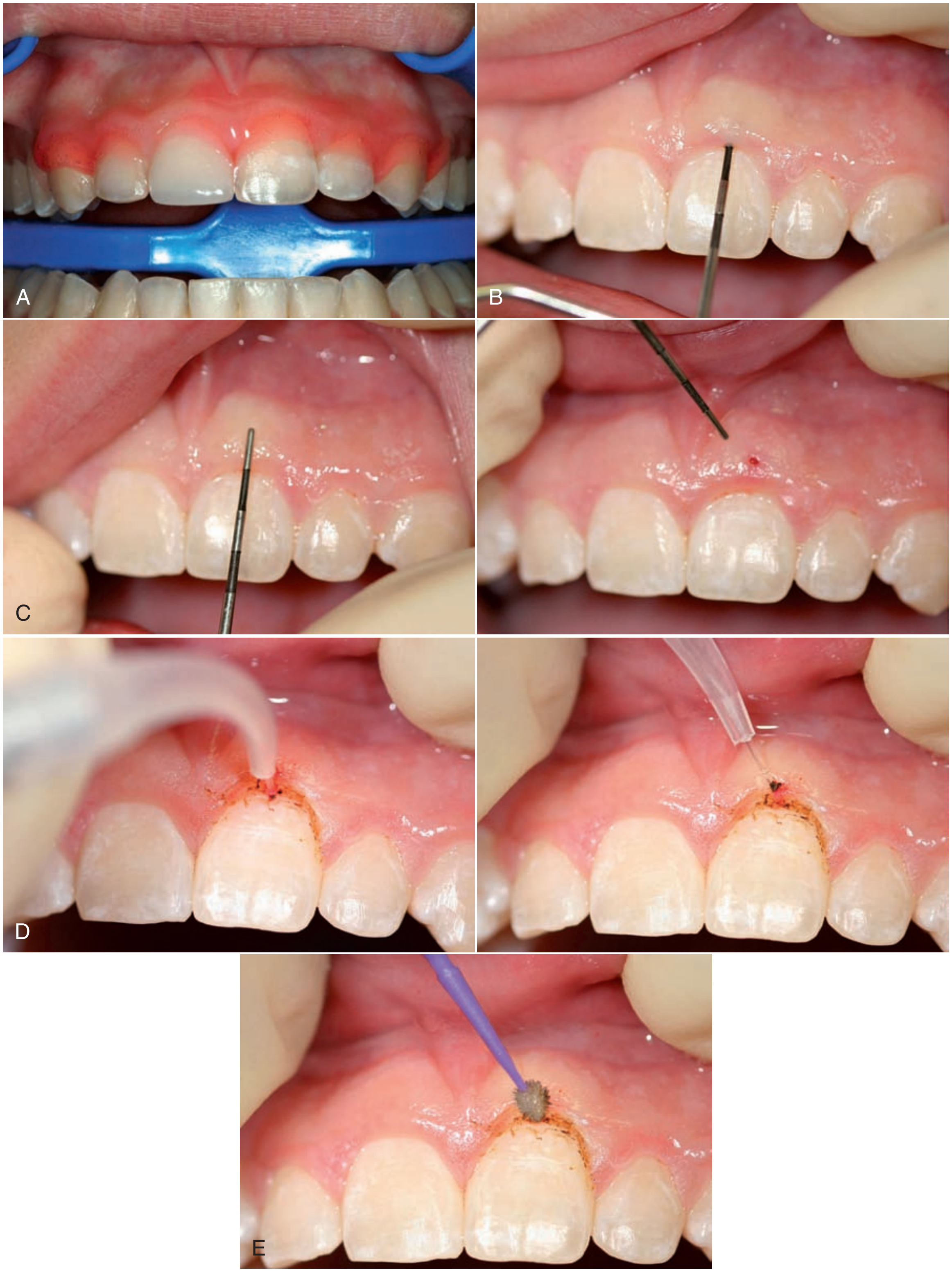


FIGURE 30-12 **A,** Compounded topical anesthetic such as TAC 20% or Profound PET is placed on the target tissue for approximately 3 to 4 minutes. **B,** A periodontal probe is used for bone sounding and pocket depth measurements. **C,** Measurements can be used to outline the proposed line of tissue removal with puncture marks made with the periodontal probe. **D,** The laser is activated and tissue is "painted away" with the fiber tip in a light contact mode, varying the angle of the tip to create ideal tissue contours. **E,** Remnants of slightly carbonized tissue, termed *char layer*, are removed with a micro-applicator brush soaked in 3% hydrogen peroxide solution.

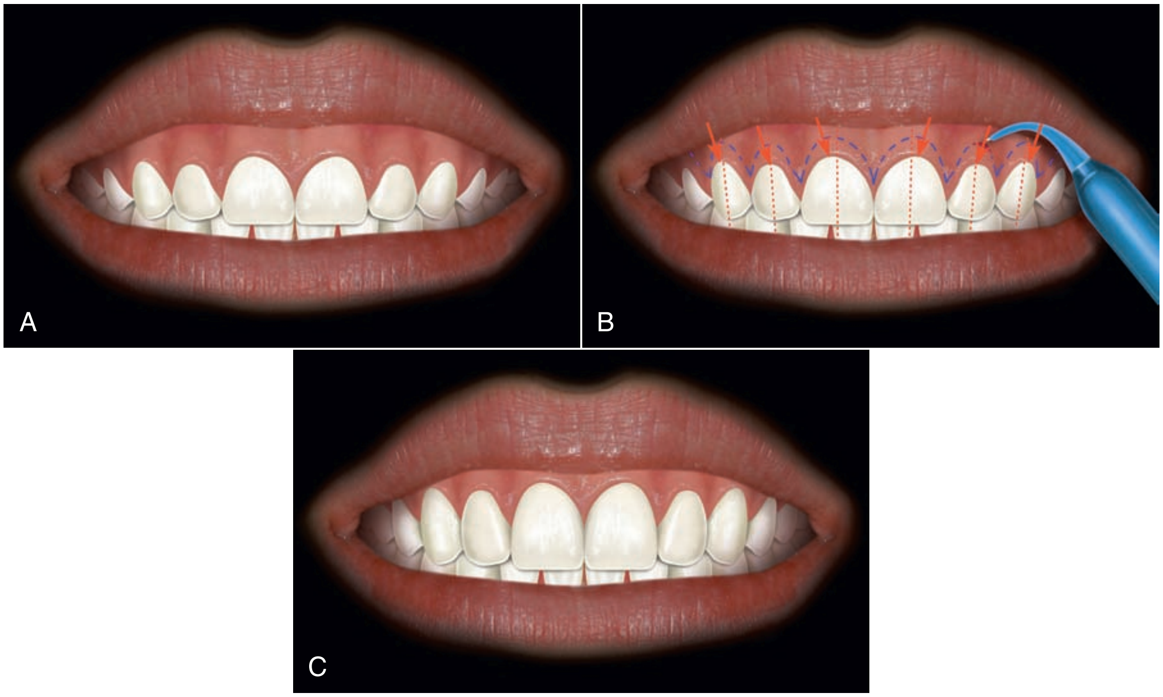


FIGURE 30-13 **A,** Excess gingival display associated with short clinical crowns is considered by most to be unaesthetic. **B,** After evaluation of biologic width, marginal tissue is removed. The gingival margins of the upper central incisors and upper cuspids should be approximately level with each other and slightly superior to the gingival margins of the upper lateral incisors. The gingival zeniths of the upper central incisors and cuspids should be positioned slightly distal their long axis centers, whereas the gingival zeniths of the upper lateral incisors should typically coincide with their long axis centers. **C,** Reduced gingival display, ideal gingival contours, and more pleasing tooth proportions dramatically improve the aesthetics of a finished case.

As a rule, aesthetic gingival recontouring is most beneficial in the upper arch from cuspid to cuspid.[62] Ideally, the gingival margins of the upper anterior teeth are positioned at or very near the inferior border of the upper lip in full smile. Display of gingival tissue in excess of 2 mm is generally considered to be undesirable. Additionally, the position, contour, and bulk of the gingiva on the crowns of the teeth often determine the perception of tooth length and width, with uneven gingival contours causing some teeth to appear too short while others appear too tall. The gingival margins of the upper central incisors and upper cuspids should be approximately level with each other and slightly superior to the gingival margins of the upper lateral incisors. The gingival zeniths of the upper central incisors and cuspids should fall slightly distal to their long axis centers, the gingival zeniths of the upper lateral incisors should typically coincide with their long axis centers, and gingival symmetry should exist from one side to the other[63] (Figures 30-13 through 30-15).

Exposure of Unerupted and Partially Erupted Teeth

Extended orthodontic treatment times are often the result of delayed eruption of teeth or compromised bracket positioning due to excessive gingival interference. Using the diode laser, both unerupted and partially erupted teeth can be exposed for bonding, and excess tissue interfering with ideal bracket placement can removed. Prior to exposure of an unerupted tooth, it must be determined that tissue removal will take place entirely in attached gingiva and that the tooth is positioned such that no bone removal will be required during the procedure. Typically, the unerupted tooth is located by radiographic examination, visualization, and palpation. After the patient is anesthetized, it is possible to determine if any bone is covering the crown of the tooth by using an explorer or scaler to puncture the overlying soft tissue and scoring the underlying hard tissue with a back-and-forth motion. Enamel will feel very hard and smooth, whereas bone will seem more porous and rough. When exposing an unerupted tooth for bonding conservative tissue removal is recommended, excise only enough to allow for reasonable positioning of a bracket or button (Figures 30-16 to 30-21).

Removal of Inflamed and Hypertrophic Tissue

Although treatment and maintenance of moderate to severe gingival hypertrophy and inflammation during orthodontic treatment are best handled by a periodontal specialist, isolated areas of transient tissue

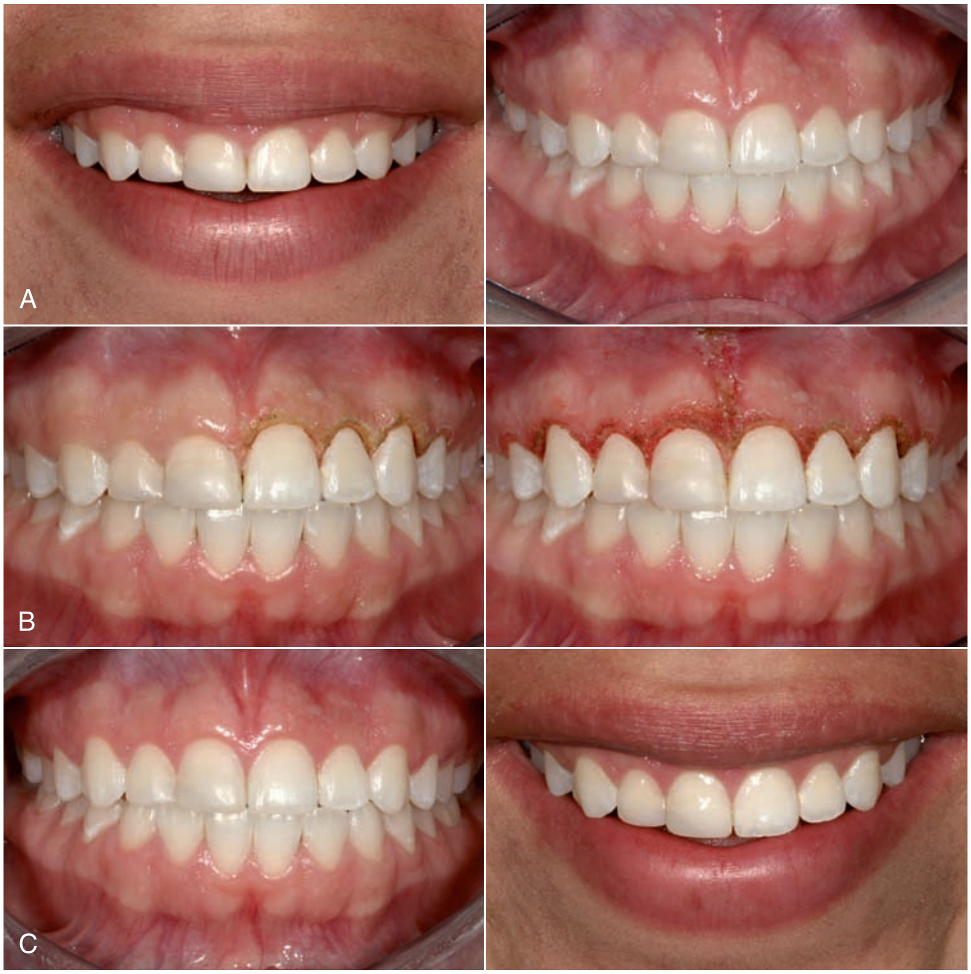


FIGURE 30-14 **A,** Excess gingival display, uneven gingival heights, and a thick labial frenum diminish the aesthetic value of this case. **B,** Aesthetic gingival recontouring and a minor labial frenectomy is performed with a diode laser set to 1.2 W, continuous-wave mode. Extended areas of surface ablation are the result of tissue beveling required to thin excessively thick gingival tissue and create more pleasing gingival contours. **C,** Postoperative results at 3 months demonstrating a significant improvement in gingival aesthetics.

hypertrophy can easily be excised with the diode laser. In addition to removing inflamed tissue, the laser also contributes to gingival health by sterilizing the area adjacent to the ablated tissue (Figures 30-22 and 30-23).

Frenectomies

A high or prominent labial frenum is often a concern when the attachment exerts a traumatic force on the gingiva or it causes a diastema to remain after eruption of the permanent canines. When indicated, a laser-assisted labial frenectomy is a simple procedure that is best performed after the diastema is closed as much as possible[64] (Figures 30-24 and 30-25).

Ankylosglossia is a developmental anomaly of the tongue characterized by a short, thick lingual frenum resulting in limitation of tongue movement. This condition can lead to problems with deglutition, speech, malocclusion, and potential periodontal problems. Ablation of the lingual frenum can be performed at any age; however, early removal is recommended (Figures 30-26 and 30-27).

Frenectomies performed with a laser permit excision of frena painlessly, without bleeding, sutures or surgical packing, and with no need of special postoperative care. Typical power settings for performing labial and lingual frenectomies with a diode laser are 1.4 to 1.6 W in continuous-wave mode.

Miscellaneous Tissue Removal

The diode laser is also very useful for a number of isolated applications such as removing tissue that has overgrown mini-screws, springs, and appliances[65] (Figure 30-28), as well as replacing the need for a tissue punch when placing mini-screws in unattached gingiva (Figure 30-29).

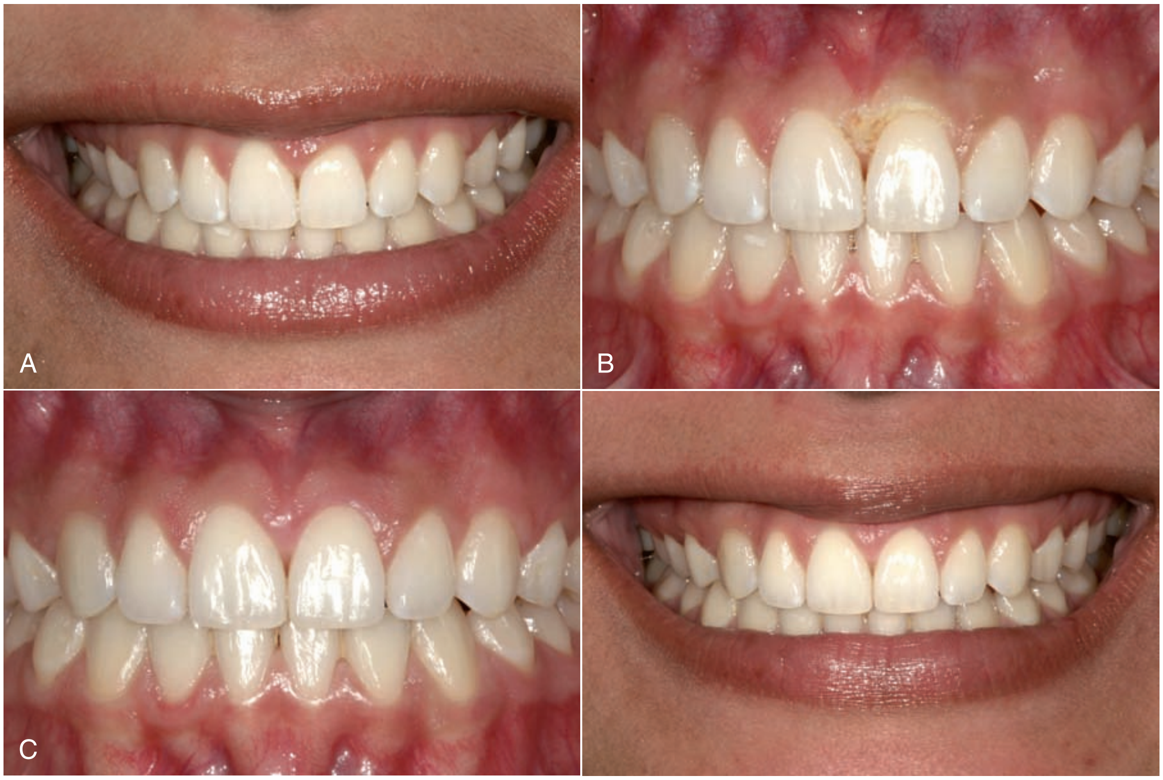


FIGURE 30-15 **A,** Significant gingival asymmetry is present on the maxillary central incisors. **B,** Aesthetic gingival recontouring is performed on the upper left central incisor with a diode laser set to 1.2 W, continuous-wave mode. **C,** Postoperative results seen at 6 weeks demonstrate a significant improvement in gingival symmetry and aesthetics.

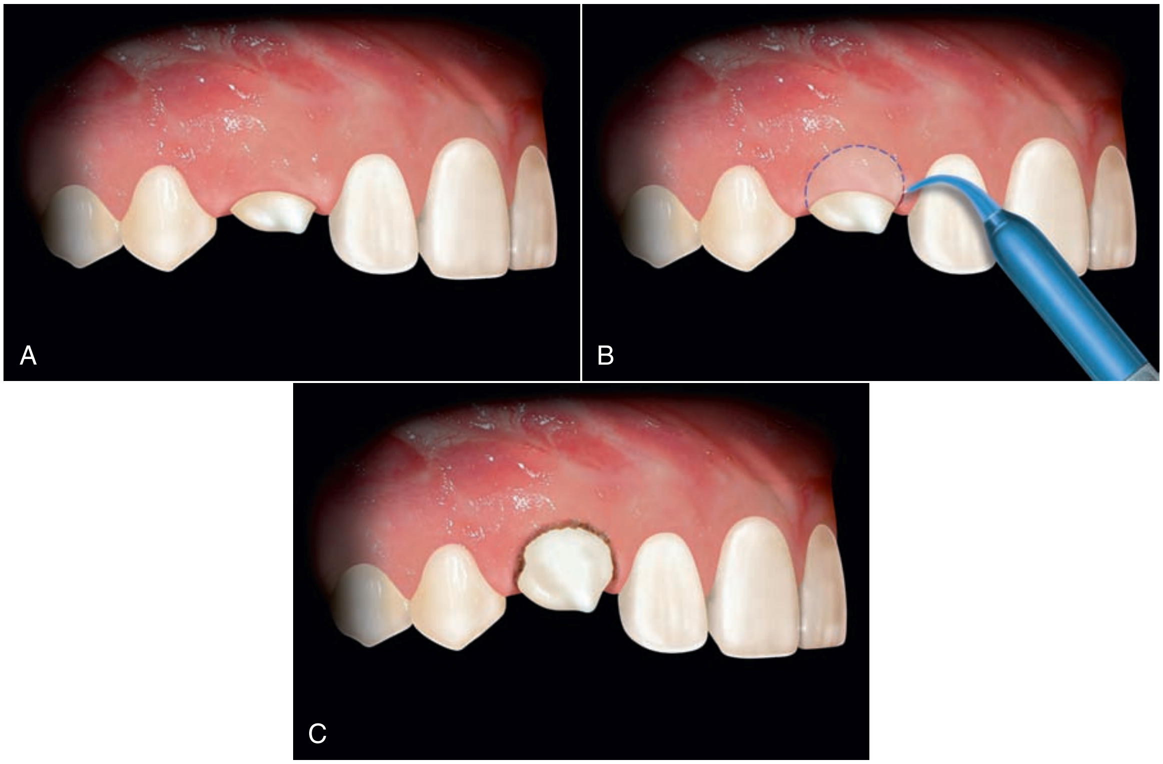


FIGURE 30-16 Treatment times can often be reduced and brackets more ideally placed by gaining access to unerupted and partially erupted teeth via laser-assisted exposure. It is imperative that any exposure be conservative and entirely in keratinized tissue to avoid possible loss of attached gingiva as the tooth is erupted into position.

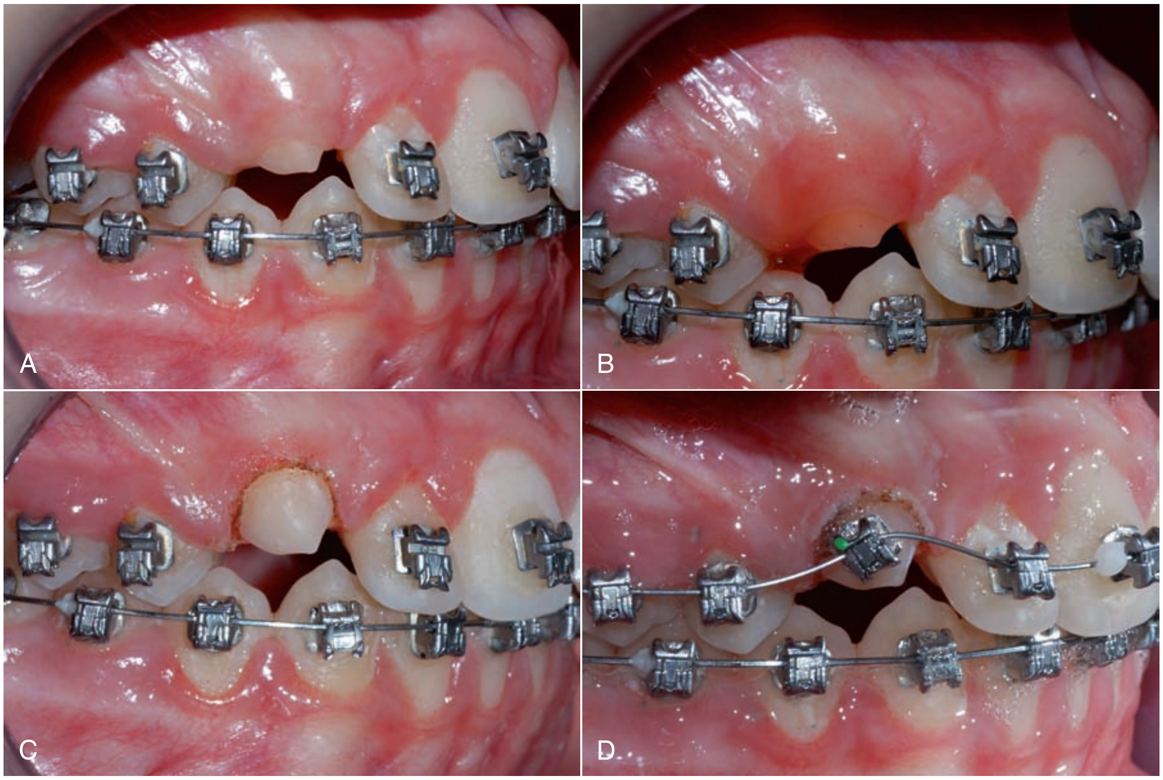


FIGURE 30-17 Access to a late erupting cuspid is achieved with laser-assisted tissue removal using a diode laser set to 1.2 W, continuous wave mode. Anesthesia is obtained with TAC 20% compounded topical anesthetic gel left in place for approximately 4 minutes. Care is taken to ensure that ablation is conservative and isolated to keratinized tissue to avoid possible attachment loss. Bracket placement follows immediately.

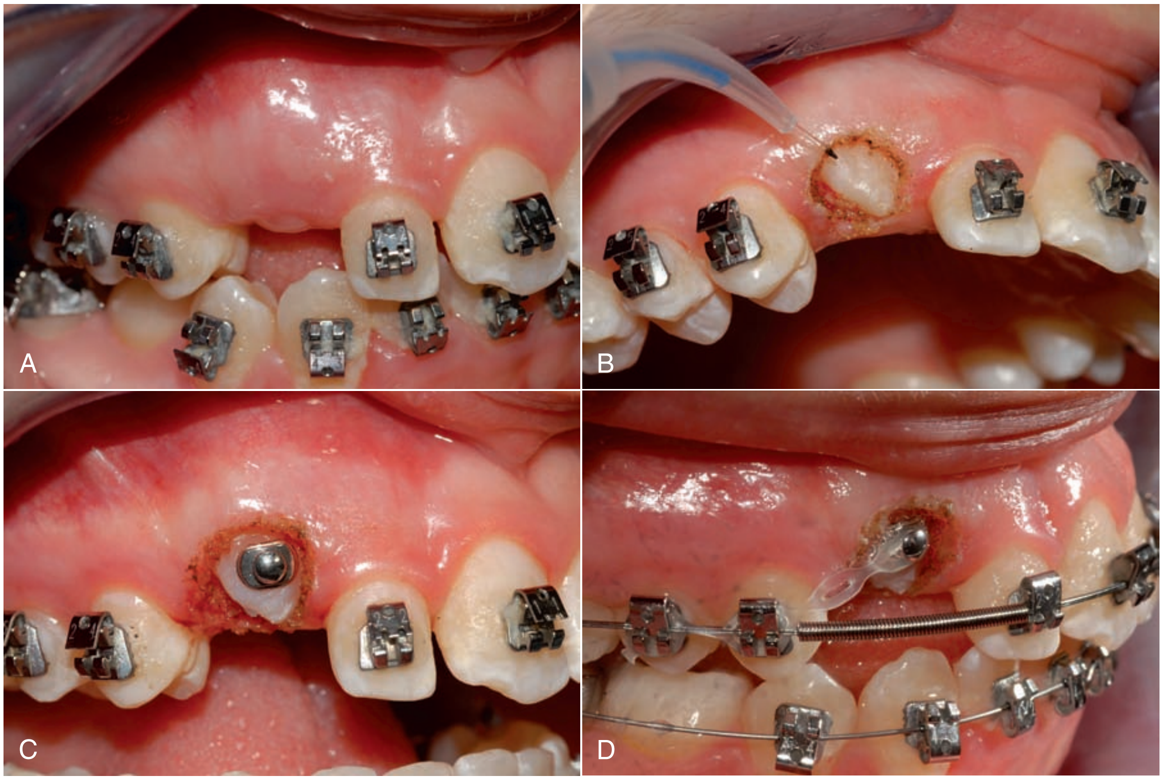


FIGURE 30-18 Access to an unerupted cuspid is achieved with laser-assisted tissue removal using a diode laser set to 1.2 W, continuous-wave mode. The tooth is located by radiographic examination, visualization, and palpation. Care is taken to ensure that ablation is conservative and isolated to keratinized tissue to avoid possible attachment loss. A button is bonded and immediately activated.

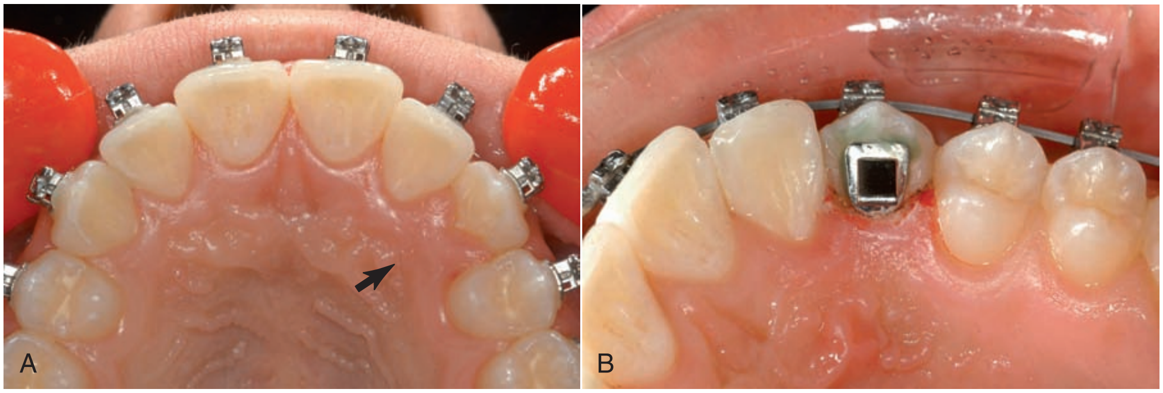


FIGURE 30-19 To facilitate placement of appliances in the lower arch, it is deemed necessary to place bite turbos on the upper cuspids. Excess gingiva covering the lingual of the upper left cuspid is removed using a diode laser set to 1.2 W, continuous-wave mode. A bite turbo was placed immediately following ablation.

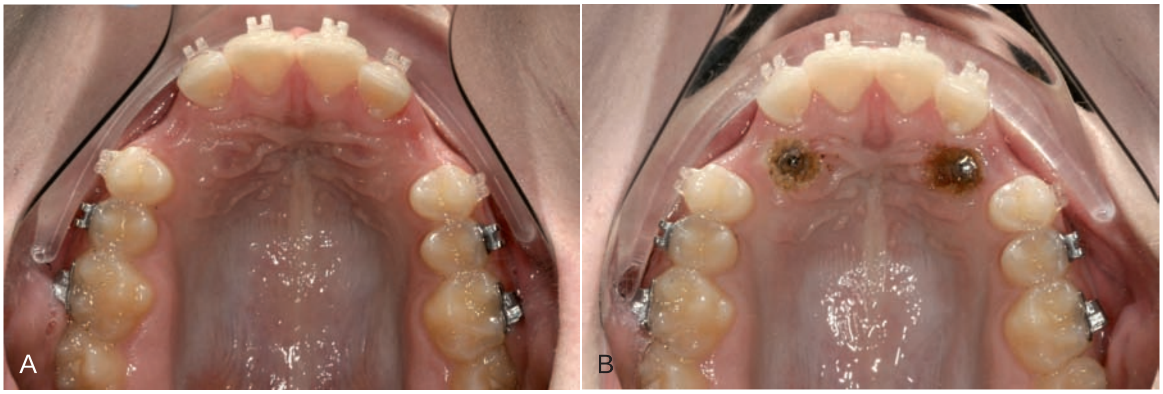


FIGURE 30-20 Access to palatally positioned unerupted cuspids is achieved with laser-assisted tissue removal using a diode laser set to 1.4 W, continuous-wave mode. The teeth are located by radiographic examination, visualization, and palpation. Buttons are bonded and immediately activated.

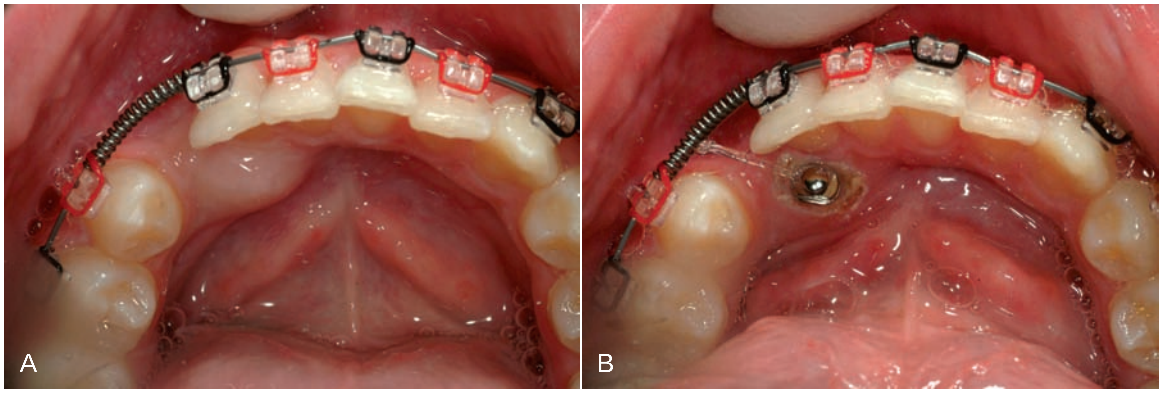


FIGURE 30-21 Access to a lingually positioned unerupted cuspid in the lower arch is achieved with laser-assisted tissue removal using a diode laser set to 1.2 W, continuous-wave mode. The tooth is located by radiographic examination, visualization, and palpation. A button is bonded and immediately activated.

Photostimulation of Aphthous and Herpetic Lesions

It has been demonstrated that photostimulation of aphthous ulcers and recurrent herpetic lesions with low levels of laser energy can provide pain relief and accelerate healing.[66–70] Although the mechanism of action is not clearly understood at this time, it is thought that pain relief may be associated with hyperpolarization of neuron membranes, alteration in the concentration of synaptic neurotransmitters, and stimulation of endorphin secretion.[71–74] Accelerated healing seems to be the result of enhanced epithelialization, along with stimulation of angiogenesis and fibrillogenesis.[75] In the case of recurrent

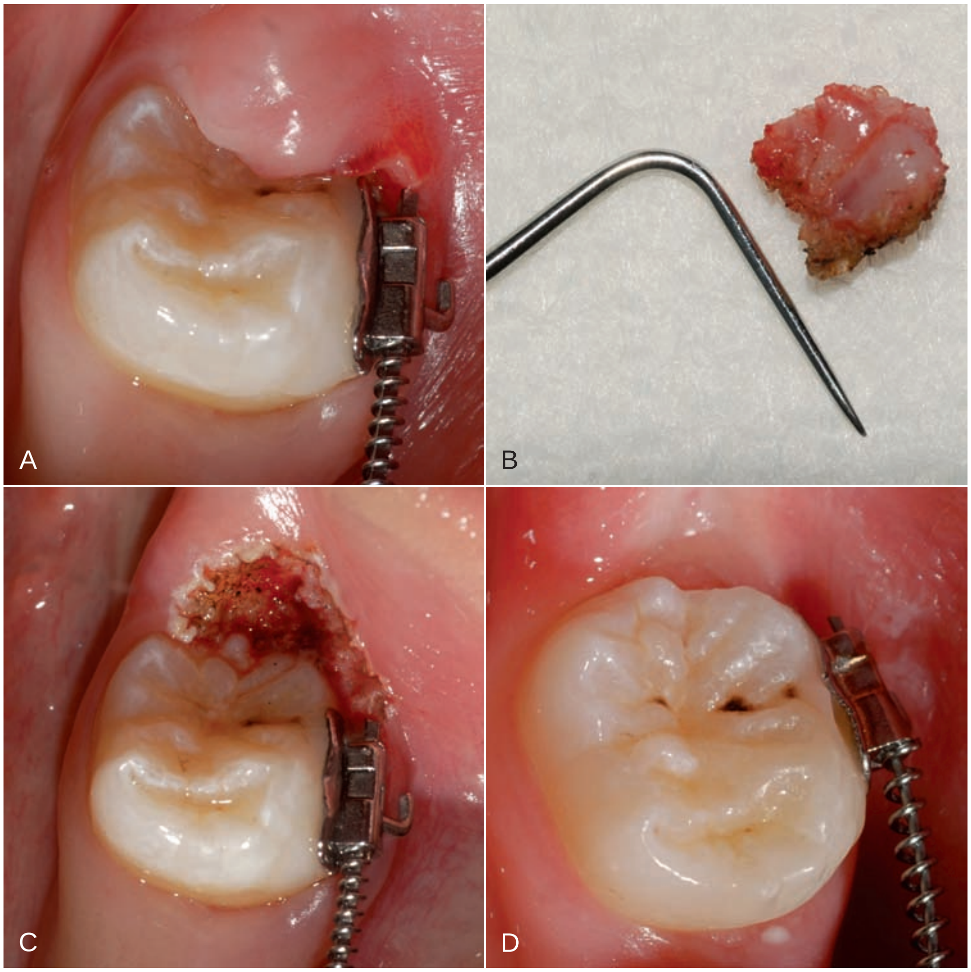


FIGURE 30-22 Patient presents with a painful, inflamed operculum on the lower left second molar. Laser-assisted tissue removal using a diode laser set to 1.4 W, continuous-wave mode, results in immediate pain relief and significantly improved access for oral hygiene. Excellent postoperative healing is observed at 1 month.

herpes simplex labialis lesions, commonly known as cold sores or fever blisters, photostimulation during the prodromal (tingling) stage seems to arrest lesions before painful vesicles form, accelerate overall healing time, and decrease the frequency of recurrence.[76]

Photostimulation therapy of aphthous ulcers and herpetic lesions using a diode laser is nonablative and performed on nonanesthetized tissue. Using a power setting of 2.0 W in continuous-wave mode, energy is delivered to the lesion with a noninitiated tip that is held several millimeters away from the tissue. Once the laser is activated, the fiber is moved around the lesion in order to deliver as much energy to the area as possible without causing discomfort for 60 seconds. After allowing the tissue to cool for approximately 10 seconds, the process is repeated for an additional 60 seconds (Figure 30-30).

SUMMARY

As orthodontic clinicians have become increasingly focused on aesthetics, treatment quality, and increased productivity, new tools and technologies have become available that allow them to produce superior results in a minimal amount of time. One such tool is the dental laser. Procedures easily performed with a dental laser include gingivectomies to enhance aesthetics, allow more ideal bracket positioning, and facilitate hygiene around orthodontic appliances; removal of tissue to expose unerupted teeth and free embedded appliances; frenectomies; and biostimulation of aphthous and herpetic lesions.

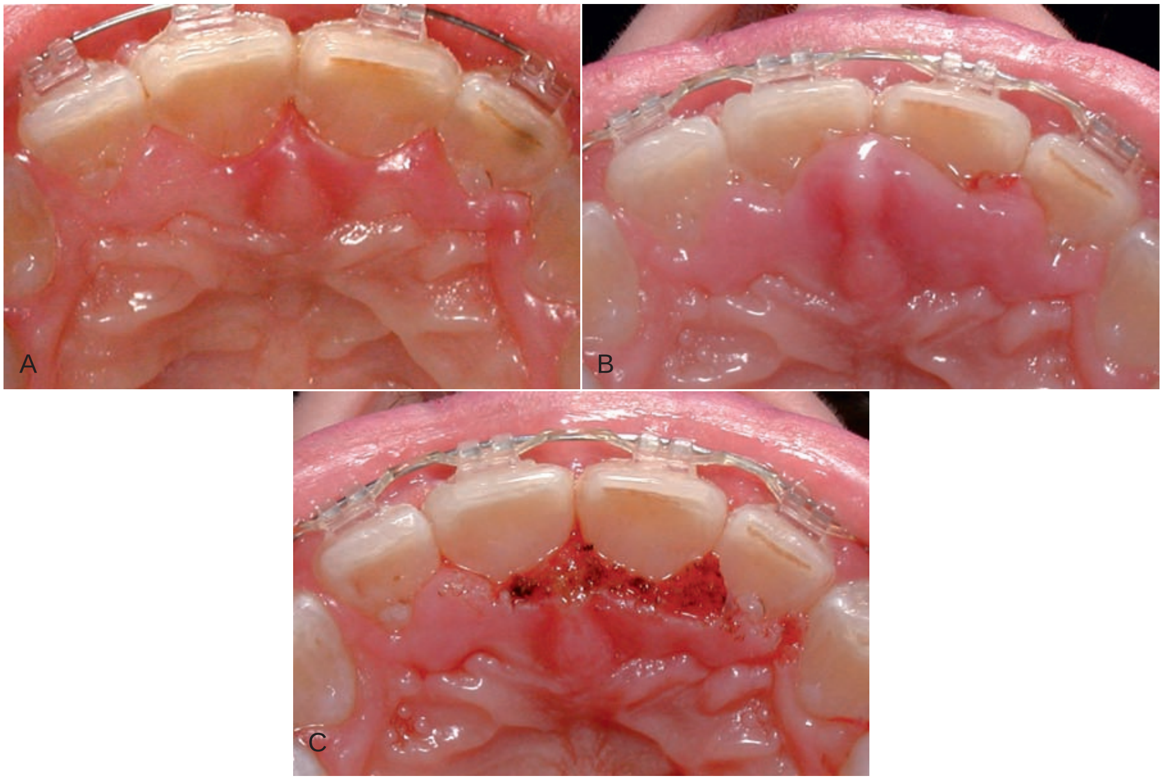


FIGURE 30-23 Patient presents with a painful, inflamed incisive papilla. Laser-assisted tissue removal using a diode laser set to 1.2 W, continuous-wave mode, results in immediate pain relief and significantly improved access for oral hygiene. Postoperative healing is observed at 2 weeks.

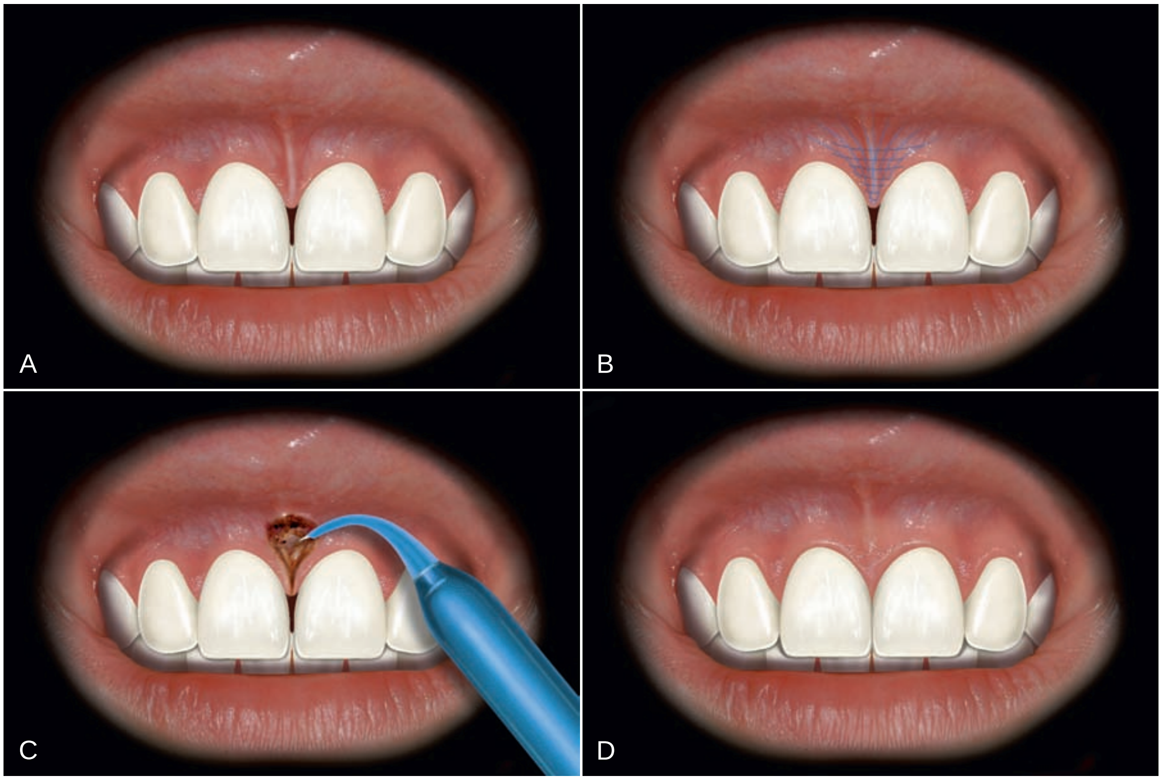


FIGURE 30-24 A high or prominent labial frenum can exert a traumatic force on the gingiva and cause a diastema to remain after eruption of the permanent canines. After anesthesia is obtained with a compounded topical anesthetic such as TAC 20% or Profound PET, the lip is stretched to delineate the frenum. Using a diode laser set to 1.4 to 1.6 W, continuous-wave mode, the reflected tissue is excised with a slow, deliberate back-and-forth motion. In cases where the frenum extends deep into the papilla, the laser is used to remove the muscle fibers all the way to the periosteum, undermining the base of the papilla while leaving the tip intact. No sutures are required as the surgical site heals by secondary intention.

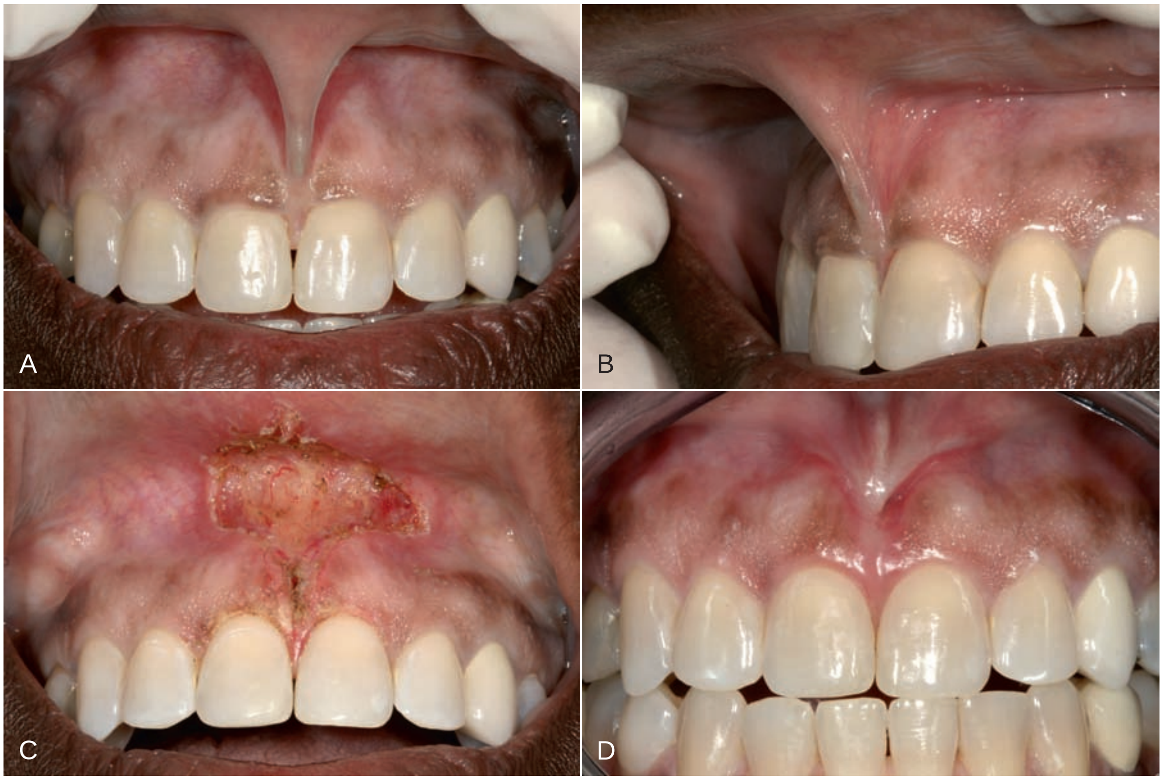


FIGURE 30-25 Patient presents with a high, prominent labial frenum that is exerting a traumatic force on the gingiva and causing a diastema. Using a diode laser set to 1.4 to 1.6 W, continuous-wave mode, the reflected tissue is excised. As the frenum extends deep into the papilla, the laser is used to remove the muscle fibers all the way to the periosteum, undermining the base of the papilla while leaving the tip intact. Note the immediate relaxation of the papilla into the embrasure following the procedure. Although some reattachment has occurred, excellent healing along with spontaneous closure of the diastema is seen at 9 weeks.

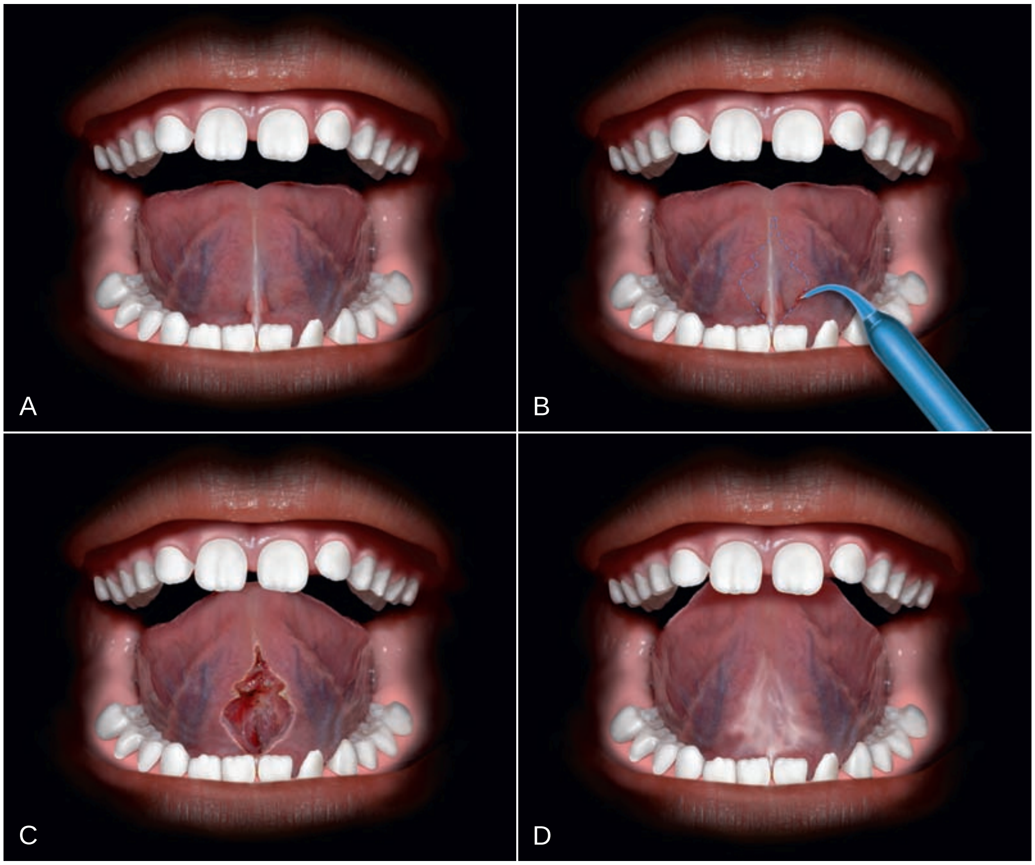


FIGURE 30-26 Ankyloglossia can lead to problems with deglutition, speech, malocclusion, and potential periodontal problems. After anesthesia is obtained with a compounded topical anesthetic such as TAC 20% or Profound PET, the tongue is stretched to delineate the frenum. Using a diode laser set to 1.4 to 1.6 W, continuous-wave mode, the reflected tissue is excised with a slow, deliberate back-and-forth motion. No sutures are required as the surgical site heals by secondary intention.

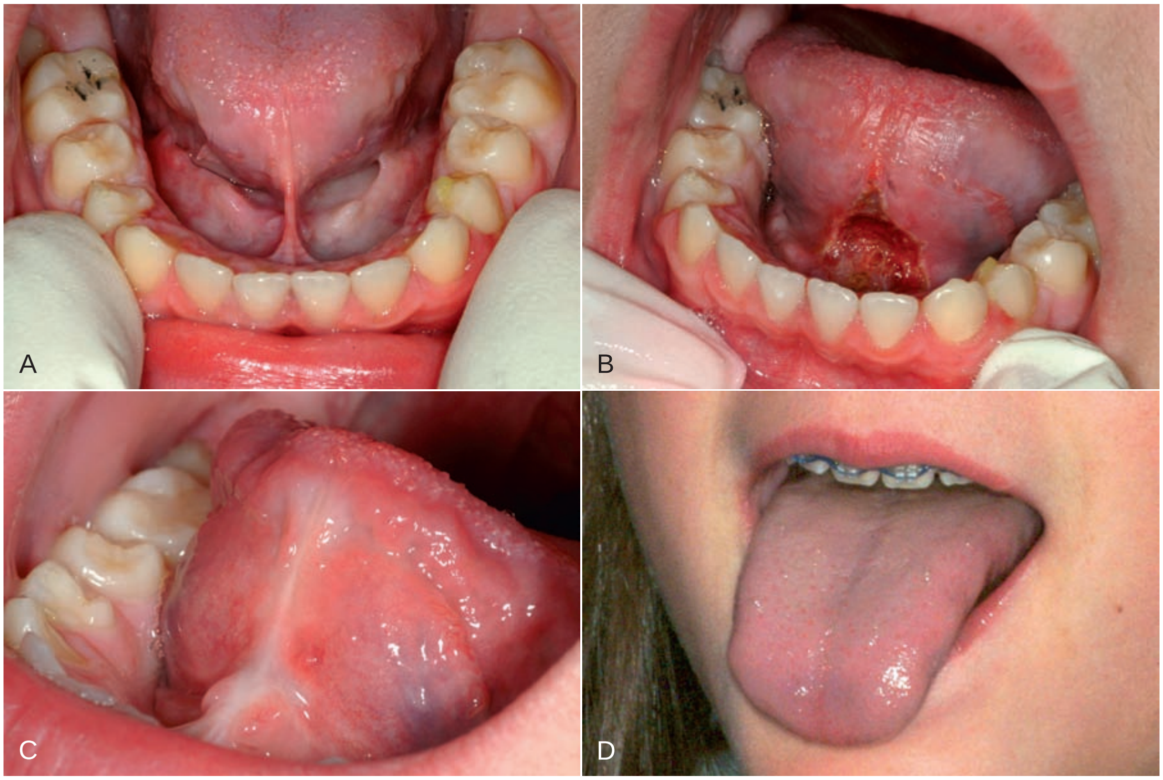


FIGURE 30-27 Patient presents with a short, thick lingual frenum and limitation of tongue movement. Using a diode laser set to 1.4 to 1.6 W, continuous-wave mode, the reflected tissue is excised. Excellent healing along with increased mobility of the tongue is seen at 4 weeks.

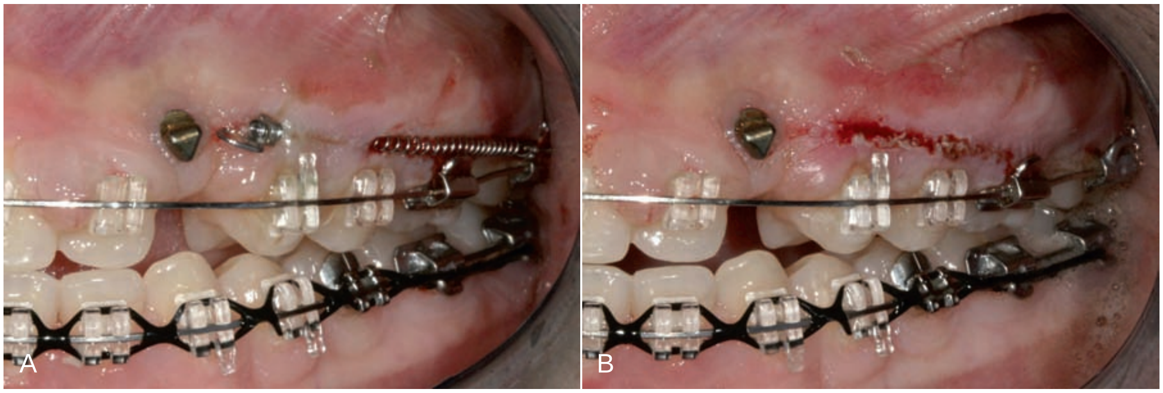


FIGURE 30-28 Patient presents with a nickel titanium spring embedded in the keratinized gingiva. The spring is released using a diode laser set to 1.2 W, continuous-wave mode.

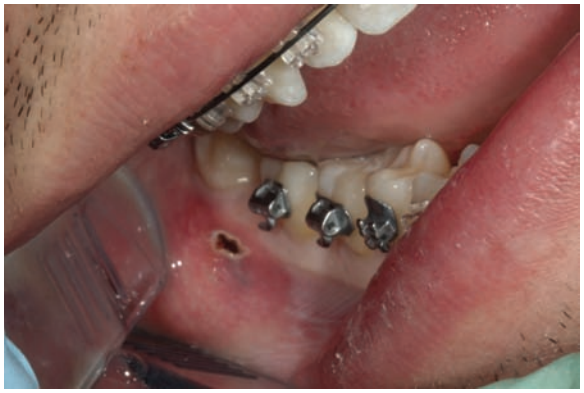


FIGURE 30-29 Placement of a miniscrew temporary anchorage device in loose nonkeratinized tissue typically requires placement of an access opening using a surgical tissue punch. A superior alternative is the diode laser, which performs the same function with excellent hemostasis and bactericidal disinfection.

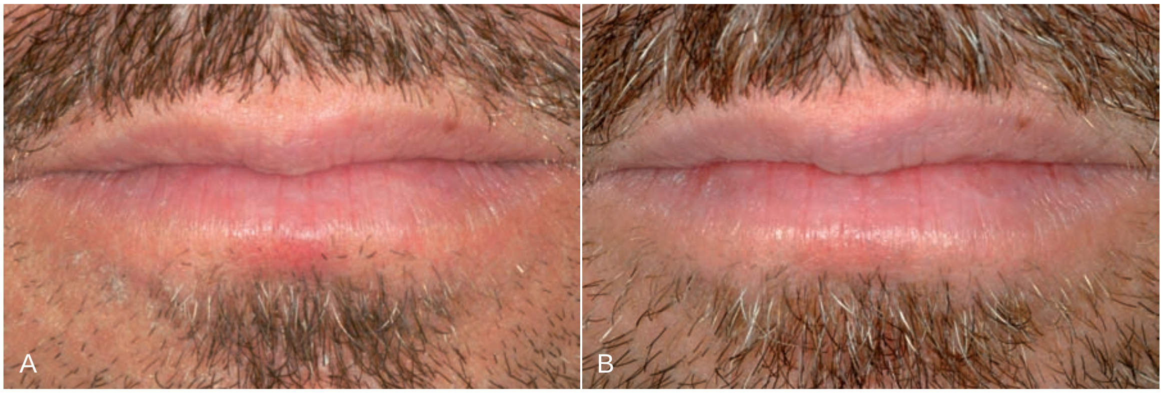


FIGURE 30-30 Herpes labialis is a common disease caused by infection of the mouth area with the herpes simplex virus type 1. Prodromal symptoms of tingling and reddening of the skin often precede a recurrence of painful and unsightly lesions. Photostimulation with laser energy has been demonstrated to arrest lesions before they advance to the blister stage, speed healing time, and prolong the duration between recurrences. Note the lesion above photographed during the prodromal stage and again 3 days after photostimulation with the diode laser at which time almost complete resolution is seen.

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